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Attacking the Soil Erosion Problem on a Nation-Wide Front - - - - - *H. H. Bennett*

Outlet Channel Design for Efficient Terracing Systems - - - - - - - - - - - - *W. D. Ellison*

Erosion Control Program of the Soil Conservation Service - - - - - - - - *T. B. Chambers*

Recent Engineering Studies in Soil Erosion Control - - - - - - - - - - - *F. O. Bartel*

The Selection of the Proper Channel Grade for Terraces - - - - - - - - - - *H. S. Reisbol*

A Study of the Various Costs Involved in Terracing Work - - - - - - - - *Q. C. Ayres*

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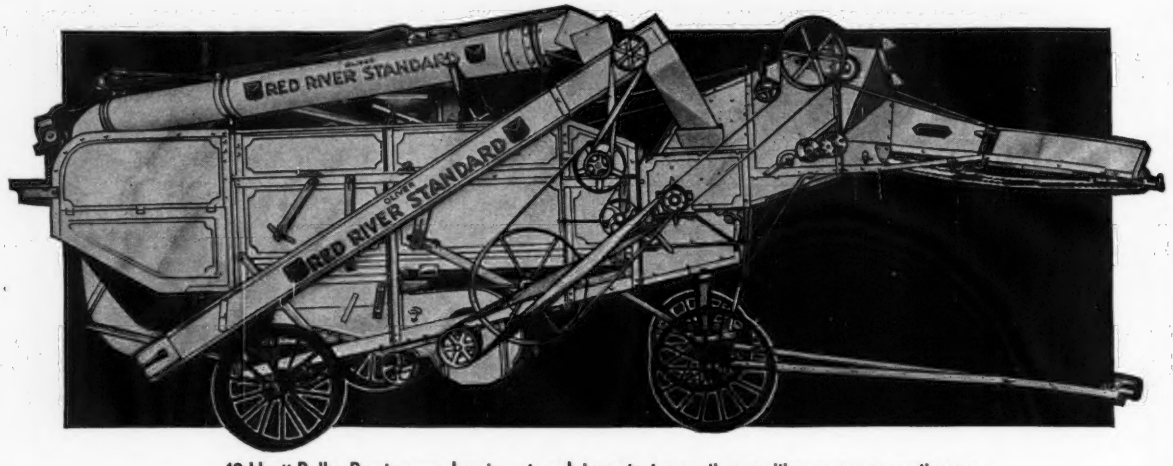

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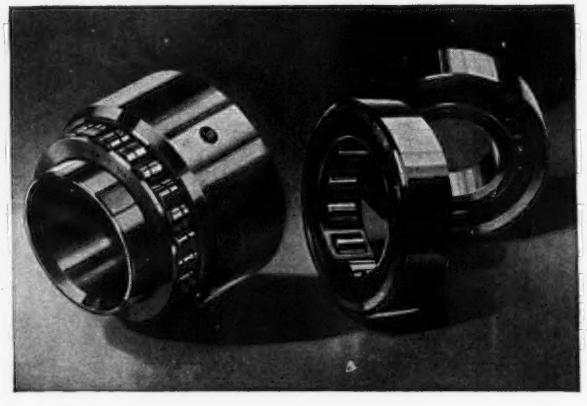

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AGRICULTURAL ENGINEERING

VOL 16, NO 8 EDITORIALS AUGUST 1935

How Much Permanence?

IN HIS ADDRESS at the 29th annual meeting of the American Society of Agricultural Engineers, Mr. K. J. T. Ekblaw sounded a note which, in our opinion, merits increasing study; namely, how long should a farm building last?

It has been a tradition in this country to pay sentimental homage to the longevity of European structures, from castles to cow sheds, and to go right on putting up for ourselves short-lived buildings. No doubt we have done too much of the temporary. But at least we have had comparatively modern buildings in which to live and work, while the five-hundred-year-old buildings of the Old World have been obsolete for about 450 years. However much we may differ with the Russians in some ways, we may admire their vision and courage in wrecking many of their too-permanent structures and replacing them with others more appropriate to the twentieth century.

Such progress as America has made—and we may boast that we lead the world—in livestock sanitation, efficient handling of stored crops, farmstead arrangement, etc., has been aided by this alleged fault of buildings which are not too valuable to be replaced, if indeed their crumbling does not force the issue and invite more modern design.

Farm buildings no longer are mere cubage or square feet under roof. With hay tools, grain elevators, milking machines and so on, they are parts of working units. As the systems of livestock management or crop handling which they embody advance, they become obsolete. As such systems in future become more complex, or at least more complete, and their advance more rapid, building obsolescence will be more and more an economic reality. It would seem lack of vision to assume a useful life of forty or fifty years, no matter how permanent the construction.

While technical changes cannot be specifically foreseen, it should be possible to plot a rough curve representing rate of obsolescence during the past fifty or a hundred years, and to project that curve as a guide to expected obsolescence in the future. With such a curve for a "ceiling," the problem of permanence becomes that of choosing construction that gives the lowest annual amortization charge when amortized over the useful life.

If obsolescence threatens to force too high a rate of amortization, it may become desirable to choose such designs and materials as lend themselves to modernization by remodelling. In any case the time is at hand for dealing with permanence not as a vague ideal, but as a quantitative factor under engineering control.

Permanence for the Soil

THE *reductio ad absurdum* of farm building permanence came to light during the 29th annual ASAE meeting when cases were cited of farms proceeding to total destruction by erosion in periods shorter than the life of the farm buildings. Of course, this is not a reason for less permanent buildings, but a vivid emphasis on the need for soil conservation.

Since the soil is the one irreplaceable agricultural asset, it is the one thing for which desired permanence should be set at infinity. If soil conservation, claiming a lion's share of interest at the annual meeting of the ASAE and of space in these pages, may seem to have stampeded the agricultural engineering profession, we make no apology. If anything, apologies are due for failing sooner to set up an adequate program of soil protection. Long ago we should have learned and heeded the lesson in the fact that the Great Wall of China remains, while the soil of China's uplands is gone.

Yet, in its engineering phases, the seeming mushroom growth of interest and activity in soil conservation is illusory. As remarked by that dean of terracing technique, Professor M. L. Nichols, the Southeast was terracing when he was a baby. Decades of patient research by Mr. C. E. Ramser and many others have laid a firm foundation for the rapidly developing program. The year past has built with amazing speed on that foundation a superstructure of national organization, allocation of responsibility, correlation of methods, and evolution of equipment for the terracing phase. It is a time when mutual felicitation may be forgiven.

Change of name of the ASAE Land Reclamation Division to "Soil and Water Conservation Division" also is seemingly tardy. Descriptively the change was long overdue, and its delay mainly a matter of finding a successor phrase which would be brief and yet correctly suggestive in content. The new name is by no means perfect, especially in brevity, but the rather general acceptance and usage of "soil conservation" lately makes the new name feasible. It implies not new objectives by men in the Division, but new recognition in national concept and policy.

Statistical Studies in Engineering

WE ADOPT for comment, somewhat critically, a few of the compiled results from a contest conducted by the farm paper *Rural Progress,* aimed to reveal the features that farmers want in a farm tractor. We do not have for study the form of questionnaire, if any, upon which replies were made, so that the influence of suggestion cannot be appraised. Neither do we know the precise basis on which the contest was announced and its effect in coloring the replies by entrants.

We are not informed as to the acreage, either average or by brackets, which these entrants represented. Neither do we know just how many of them are tractor owners,

have had tractor experience, or are likely to become tractor owners; in short, what background they have for their preferences, or how significant they may be as samples of potential tractor markets. And it is indicated that the features they ask for are to be in an "ideal" tractor—which is not necessarily the same as they would consider most practical or be willing to pay for.

In the matter of traction members they voted by more than 12 to 1 for rubber tires in preference to steel wheels or tracks. Yet the equipment of tractors actually sold at about the time of the contest showed this ratio roughly reversed. This discrepancy between the ideal and the dotted line is no trifle to be overlooked.

The 15,573 replies tabulated were from Illinois, Indiana, Michigan, Wisconsin, Ohio, Iowa, and Minnesota. This distribution of origin bears on the overwhelming ratio of more than 100 to 1 favoring the row-crop type as against the "standard" four-wheel construction. Even so, the ratio is exaggerated in comparison with actual purchases.

Size of unit and nature of service as implied by the row-crop preference may have a good deal to do with fuel "ideals." The Diesel devotees were outnumbered 12 to 1 by those favoring gasoline. Indeed, despite a generation of emphasis on heavy fuel for tractors, gasoline was specified by nearly 60 per cent as many as spoke for kerosene or distillate. Only one in 238 listed alcohol as the ideal fuel.

Among a varied list of desired mechanical features, those leading with each having about half the number of entries were cylinder sleeves, ease of attaching implements, and belt pulley. That the belt pulley—almost as much taken for granted among the tractor-wise as the fuel tank—should be mentioned as a feature suggests something amiss. The issue of foot vs. hand clutch was taken up by less than 10 per cent of the entrants, with the foot clutch leading 5 to 2. Valve inserts were specified by about 25 per cent. That almost the same number call for improved brakes seems reasonable until it is noted that no mention is made of turning brakes as such, and it becomes perplexing to reconcile the demand by nearly 10 per cent for "high traction differential" with the characteristics of a row-crop machine.

Unless given point by some qualification not apparent from its bare mention in the recapitulation, citing of "governor" as a feature by nearly 25 per cent suggests unfamiliarity with prevailing tractor practice. It may be significant that one in seven wants a starter, and one in nine calls for lights. Yet in childlike faith only one in 30 mentions a generator.

If we went on to cite the ideal capacity in terms of plows pulled, speed, number of cylinders, and weight—to mention only a few items of more palpable nature—we should find again that trends established in actual practice are reflected, but in highly exaggerated degree. It may be suspected that the objective of the contest and related advertising were rather potent suggestion factors. This is said in no spirit of carping criticism, for this writer has had enough experience in drafting and compiling questionnaires to be most sympathetic toward the difficulties thereof.

Our purpose, rather, is to emphasize those difficulties and urge every effort to avoid the sources of error, both in the psychology of approach and in the subsequent statistical treatment. The survey method is too valuable to be used in less than the most reliable fashion, whether the results are to be used for engineering guidance or for promotional material.

Nor do we single out the present subject matter for more than a current example. We may well revert to the survey made last fall by the ASAE wheel equipment committee on rubber tires for tractors. Though subjected to scrutiny by sundry persons, including this writer, to minimize sources of error, the element of suggestion could not be entirely excluded. More serious, that questionnaire went to owners of air tires. Obviously they believed they had, and most of them did have, conditions favorable to the use of such tires. That circumstance should be, and among engineers no doubt was, borne in mind in evaluating the compiled and published findings.

Looking to the future, in which statistical surveys promise to be increasingly used by our profession, it seems proper to propose a closer and perhaps more formal alliance with the increase of statistics.

For Fence Engineering

IT WAS LOGICAL, and might well be prophetic, that an entire session of the Structures Division, during the 29th annual meeting of the American Society of Agricultural Engineers, was devoted to farm fencing. Taking the country as a whole, it seems sure that no other part of the farm plant is so far gone into disrepair and disorganization. It seems equally obvious, in general, that few structural improvements are so quickly self-liquidating.

While there are piece-meal contributions to sundry detailed phases of farm fencing, there is no orderly literature covering the subject in a way both comprehensive and soundly technical. No one can with any assurance define what is an optimum fence for a stated situation. Fencing evidently is a vernacular art not well organized empirically, much less engineered on a foundation of basic studies. As such an art it has been more efficient than could be expected —another testimonial to the judgment and resourcefulness of the American farmer.

Several developments now dictate a dignified program of fence engineering. One consists of technical advances by fence manufacturers during the years that fences (as farm plant) retrogressed. These are mainly metallurgical improvements to achieve longer fence life. In this phase of fencing industry is doing its part, and it is logically about as far as the province of industry goes. Determination of optimum height, spacing, wire size, etc., in relation to service requirements would seem to be a job for agricultural engineers and animal husbandmen.

While it has not progressed as might be wished by our profession's participants therein, the ASTM program of fence-testing creates an occasion and should afford data for accelerated activity in fence engineering. Terracing and other phases of soil conservation, and indeed all land-use progress, create new need for fencing, or need for new fencing.

Though its work was brought to an untimely end by economic troubles, the Farm Fence Institute lived long enough to demonstrate the need for fence engineering as a form of farm management, and that farmers were not really so indifferent to fencing as fence sales curves might seem to indicate. Whether that Institute or something akin to it should be given another chance in a more normal economic atmosphere is not for us to suggest. We do believe that the engineering work, both research and extension, toward which it pointed should be promptly organized and systematically pursued.

Attacking the Soil Erosion Problem on a Nation-Wide Front[1]

By H. H. Bennett[2]

IT IS A PLEASURE and a great privilege to meet again with the American Society of Agricultural Engineers. The last opportunity I had of this kind was at your Dallas, Texas, meeting in June 1929. The scene with respect to what we are doing about the erosion problem has changed greatly since then; it has developed enormously alone lines of actual combat against a great national evil.

In 1929 we were emphasizing the investigational and educational phases of the problem. These activities are being continued, and in an effective way, I think. But now we have gone into the fields with CCC camps, with large demonstration areas, and with other projects; and we have accomplished a great deal of work. Much of it has been tremendously effective work; some of it not so good. But even that which has failed to give optimum results has served a purpose, for we have learned much from our mistakes.

Then too, there has been a recent widespread and helpful recognition of the problem. States and local communities have awakened to a realization that concerted action to curb erosion is necessary, if the productivity of a very large share of our agricultural lands is to be preserved.

This development of interest on the part of states, counties, communities, and the nation represents a tremendous stride forward. Its significance is obvious.

I should like to talk today about all phases of the soil conservation movement, including the constructive measures now being adopted by many states and their political subdivisions. But it will be more pertinent to confine my remarks chiefly to the program of the federal government, since I am naturally most familiar with that phase of erosion control activity.

After nearly a decade of research and experimental work, the government started its first comprehensively coordinated program of erosion control in September 1933, when the Soil Erosion Service was created as an emergency agency of the Department of the Interior.

Two months ago, the Service was transferred to the Department of Agriculture, renamed the "Soil Conservation Service" by Act of Congress, and given full status as a permanent agency in the governmental structure.

Today the organization is looking to the future with plans for an intensive national program. I want to tell you something of these plans, but first I should like briefly to explain our objectives and outline the work already done.

* * * *

Stated broadly, our objective is to foster a demand on the part of all the people, and at the same time to show the way for the preservation of that rural independence so richly productive of the human and material values which led to the development of this nation of fabulous wealth. This end cannot be accomplished unless we save the soil from which these values spring.

More specifically, the aims of our program are, first, to demonstrate that the impoverishment and destruction of our remaining areas of good agricultural land can be curbed to a very large degree; and second, to lay the foundation for a permanent national erosion control program of scope sufficiently broad to meet the acute land crisis created by wasteful methods of land utilization.

To these ends, there has been set up a nation-wide network of demonstration projects ranging in size from 25,000 to 16 million acres each. Here the farmers of the country are shown by actual, concrete example that it is both possible and practical to halt the inroads of erosion on the fertility, even the very physical substance, of their fields.

These demonstration areas are very much like a show window; and above all else the display must be convincing.

The work must be good enough to impress the farmer who comes to inspect it—and it must be absolutely practical. We must not give the farmer an opportunity to say, "Well, Uncle Sam can afford to do that kind of work, but it's too expensive for me!" Rather, we must perform our task in such manner that he will say, "Now why didn't I think of that," and then go home and apply what he has seen to his own land.

* * * *

Since these demonstration projects form the nucleus of the Soil Conservation Service program, they must be located and executed with extreme care.

Each area is selected with due consideration of the varied problems it presents, the adaptability of the land to a unified, effective demonstration program, and the willingness of farmers and landowners to cooperate and help carry on the work.

Comprehensive, practical plans are then worked out for the control of erosion and the reduction of floods and silting over all the lands within the watershed areas selected for

[1] An address before the 20th annual meeting of the American Society of Agricultural Engineers, at Athens, Georgia, June 1935.

[2] Chief, Soil Conservation Service, U. S. Department of Agriculture.

the demonstrations. These plans are based on the physical and chemical characteristics of the soils involved, the topography, climate, vegetation, and the agricultural practices of the area. That is to say, the program is based on the needs and adaptability of the many different kinds of land involved.

In the detailed working plans, careful consideration is given to the needs of the farm as an economic unit, in order that property owners or operators may not suffer financial loss.

When the plans are in shape, the government enters into voluntary five-year agreements with farmers of the demonstration area, under which the latter agree to carry out the land-use practices advocated and to contribute a fair share of the labor and materials necessary for completion of the work on their farm.

In return, the government agrees to lay out the work, to provide supplementary labor and material, and to furnish seed and certain other materials which the farmer may not be able to supply.

Not until such cooperative agreements are completed is work actually started. Then the most modern, inexpensive, and practical erosion control measures are put into operation, not as separate or distinct methods, but in a carefully synchronized, coordinated program in which they are used to support one another, each constituting an indispensable part of the whole.

These measures have been developed by various agencies, including the agricultural experiment stations, the erosion stations, the farmers themselves, and the Soil Conservation Service. In other words, all known practical measures, whatever their origin, are being employed wherever adaptable.

The Service itself has devised and developed a number of extremely valuable measures of erosion control. It has developed a very efficient method of plowing between terraces, and in its gully control work has originated new types of check dams which have withstood the impact of terrific floods in a highly effective way.

In the eastern section of the country, methods of controlling some types of gullies have been completely revolutionized, both as to type of dam and the uses of supporting vegetation. On the South Tyger River project in South Carolina, for example, a unique method has been devised whereby gully erosion can be controlled through simple labor and vegetation. Old type check dams have been outmoded in this Piedmont region.

* * * *

Although the demonstration projects have been, necessarily I think, the most vital factors in the program, the Service has undertaken many related activities.

Probably the most important of these has been the completion of a nation-wide, county-by-county reconnaissance survey of erosion conditions, and the translation of the results into an erosion map of the United States, which very soon will be available to the public. One hundred and twenty erosion specialists under the direction of the Soil Conservation Service covered every county in the country in two months' time to make this survey, and the completed map probably is one of the most comprehensive charts of actual soil conditions ever made.

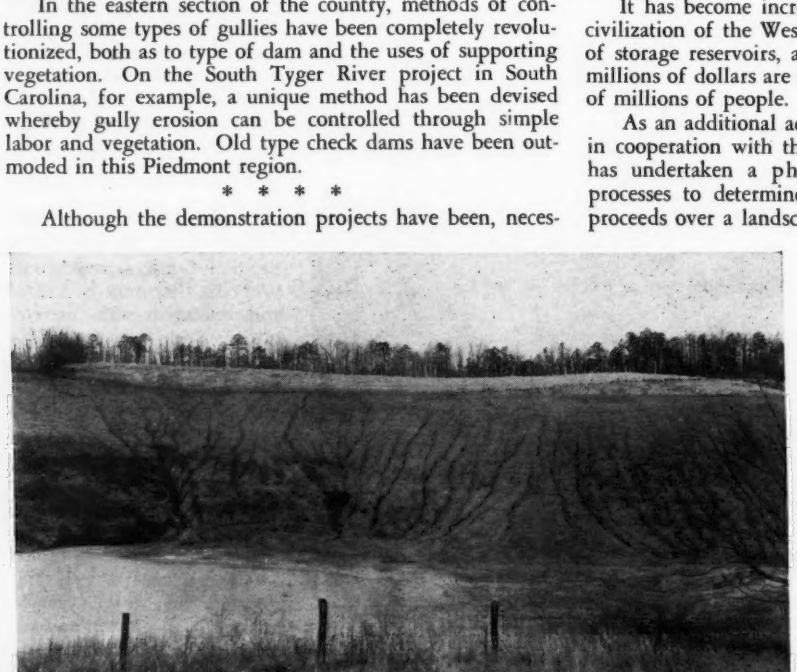
Another activity involves the detailed mapping of 230 square miles now being inundated behind Boulder Dam. In cooperation with the Reclamation Service of the Department of the Interior, and the Coast and Geodetic Survey of the Department of Commerce, this survey is being made in order that topographic changes likely to be caused by deposits of erosional debris in the reservoir can be measured through the instrumentality of future comparative surveys. This activity is regarded as an important preliminary step in plans being devised for protecting Boulder reservoir from destructive sedimentation.

On the subject of sedimentation, the Service is conducting other surveys and studies as a natural corollary of its erosion control work. In this way the rate of sedimentation in stream channels and reservoirs constructed for power and water supply purposes will be determined.

Results already obtained from these studies show that the problem of reservoir and stream silting is closely related to soil erosion. Of 56 reservoirs studied in the southern Piedmont section, east of the Appalachians, 13 major reservoirs were found to have been silted to the top of the dam within an average of 29.4 years, with scores of lesser reservoirs filled within still shorter periods. This information, together with previously accumulated information of the same nature, shows that we have in this field still another major national problem that must be met if it is humanly possible to do so.

It has become increasingly apparent that the irrigation civilization of the West is endangered by this rapid silting of storage reservoirs, and that investments of hundreds of millions of dollars are menaced as well as the social security of millions of people.

As an additional activity, the Soil Conservation Service, in cooperation with the National Science Advisory Board, has undertaken a physiographical study of erosional processes to determine the normal rate at which erosion proceeds over a landscape undisturbed by cultivation, graz-



"There must be a permanent program of erosion control," says Mr. Bennett. "if this country is to maintain permanent prosperity on its agricultural lands. Continuing land wastage seriously threatens the welfare of large farming populations, and eventually will result in partial or entire abandonment of many sections, if not vigorously combatted without further delay. And thus unrestrained soil erosion directly and indirectly menaces the safety of the nation, for the very roots of the republic are fastened in our farm and grazing lands, more than seventy-five per cent of which is subject to the impoverishing effects of erosion."

ing, structures, highways, and other cultural features. There is definite need for this information in the formulation of a long-time farm-management program and in order to ascertain the effectiveness of erosion control measures.

* * * *

All this, however, leads to my next point, which already has been indicated. There must be a permanent program of erosion control if this country is to maintain permanent prosperity on its agricultural lands. Continuing land wastage seriously threatens the welfare of large farming populations, and eventually will result in partial or entire abandonment of many sections, if not vigorously combatted without further delay. And thus unrestrained soil erosion directly and indirectly menaces the safety of the nation, for the very roots of the Republic are fastened in our farm and grazing lands, more than 75 per cent of which is subject to the impoverishing effects of erosion.

This is not a mere opinion. It is a statement based on physically determined facts. The remedial step that inevitably must be taken is the application of a coordinated land-use and land-protection program in accordance with the specific needs and adaptabilities of all types of valuable land needing treatment. Putting off the work means only a larger, more difficult, and costlier job in the future. This task of protecting the land against increasing impairment and destruction must be persistently continued from now on. It is one of the most difficult that mankind ever undertook, and in America it is certainly one of the most pressingly important undertakings now confronting us, as well as one of the most intriguing fields inviting the attention and service of the specialist, whether agricultural engineer, agronomist, forester, biologist, or economist.

To meet this need for a permanent national program of erosion control, the Soil Conservation Service is developing as rapidly as possible a definite program for 1935 to 1937 and for the future.

Several distinct fields of operation are involved; namely, erosion control demonstration projects, ECW camps, emergency relief work, research investigations and surveys, operation of erosion nurseries, educational activities, and cooperation with state and federal agencies.

Demonstration projects are planned for agricultural communities where erosion is known to be a serious problem. These units are designed to show not only the effectiveness of practical measures of erosion control, but also to establish definitely the safest regional land-use procedure, at least in so far as the physical characteristics of the land are involved.

The project areas would for the most part approximate 25,000 acres in extent, and would comprise, wherever practicable, complete watersheds, at least one for each important agricultural district or distinct land region. At present a number of states are being partitioned into problem regions through state planning boards. The Soil Conservation Service is doing this also, on the basis of erosion conditions and other physical characteristics of the land.

Meanwhile, although a number of projects are under way, no work is being done in several states having important erosion problems. To an even greater extent are there distinct regions without demonstration units. These states and regions will be given priority in the establishment of new projects.

* * * *

Already three wind erosion control projects are under way. One is located near Dalhart, Texas; one in Colorado; and the other in South Dakota. Under plans for the future, this work will be expanded.

The experience of recent years has clearly indicated that,

This picture shows an extreme case of unchecked erosion. The result is complete destruction of valuable farming land

if erosion by wind is neglected, much valuable land inevitably will be seriously impoverished or ruined. As a matter of fact, several million acres of formerly good land already have been seriously impaired or ruined. Experience has also shown that protection of the land, that affected by water as well as that affected by wind, is not incompatible with production. Certain measures of common-sense land use applied in a permanent way, will afford the necessary soil safeguard and, at the same time, permit production to continue. Briefly, these are, with respect to land subject to wind erosion: (1) Preservation of crop residues or stubble to anchor the soil; (2) strip plantings of adaptable grasses and other plants; (3) permanent windbreaks of trees and shrubs and other measures for the establishment and maintenance of protective plantings; (4) moisture conservation through level terracing; (5) improvement in methods of cultivation, such as leaving the surface rough and listing on the contour; and (6) prevention of overgrazing of both grains and grasses.

* * * *

Quite naturally, in order to make the national erosion-control program effective, it will be necessary to carry out careful investigations concerning the relationships between erosion and the various conditions of soil, slope, climate, and methods of land use.

Ten erosion experiment stations formerly operated under the Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering have been transferred to the Soil Conservation Service. These stations and two experimental projects now being operated by the Service will be continued and expanded.

Additional research work will pertain to sedimentation and hydrological studies, the behavior of silt-laden streams, stream bank erosion, and aerodynamic investigations in the field of wind erosion.

* * * *

The Service will also operate several soil erosion nurseries which were formerly a part of the Bureau of Plant Industry. These stations will supply certain needs as to planting stock and seed, especially of plants not usually handled by commercial dealers.

* * * *

These activities lead squarely in the direction of the long-range program of the Soil Conservation Service, which contemplates the initiation of measures on all valuable land now suffering from erosion within about 10 years, in order to secure reasonable control of erosion within about 20 years. The program also seeks to establish preventive measures within a generation on practically all of the better

(Left) A typical example of a terraced field. (Right) Strips of oats between terraces. Strips of close growing vegetation planted along the contour also reduce runoff and soil loss

lands subject to this hazard. This objective was endorsed by the National Resources Board in its report of December 1, 1934, which Board had the assistance of months of study by a great variety of specialists, including engineers and representatives of practically every other specialized field having to do with the conservation and economic use of our major national resources.

This program should include the following elements:

1 An adequate expansion of demonstration projects to cover effectively all representative erosion regions, and to furnish a satisfactory means of demonstrating and educating farmers in the proper methods of protecting their land from impoverishment.

2 The start and completion of all erosion work needed on lands owned or controlled by the United States and on lands draining into federal reservoirs.

3 Application of practical erosion-control measures on large watersheds in the various agricultural regions of the country, in cooperation with conservancy districts, erosion control associations, or similar organizations.

4 An adequate research program conducted on such scale as to provide the fundamental information upon which an effective national erosion control program must be based.

5 An effort to educate the public in the best methods of controlling erosion and in the need for carrying on this type of work, in cooperation with other organizations, such as the extension service and vocational teachers.

* * * *

There seems to be small need for me to tell you, who are so intimately associated with the land, of the benefits to be obtained from such a program of erosion control. You know there is genuine need for such a program.

But briefly I will list some of the more outstanding benefits:

1 Impoverishment and destruction of farm lands would be prevented.

2 Stability of agricultural communities would be maintained, in contrast to the present situation in many localities characterized by an increasing extent of submarginal land and progressive farm abandonment.

3 Better control of floods.

4 Curbing of dust storms.

5 Economic use of meteoric waters and consequent decrease of the hazard of drought.

6 Protection of large investments in reservoirs through reduction of the hazard of silting, and the conservation of human and economic values dependent on such reservoirs.

7 Safeguarding of the western grazing industry.

8 Conservation of the public domain and Indian reservations.

9 Preservation of ancient Indian and Mexican civilizations in the Southwest, such as can be saved only through the conservation of essential land resources.

10 Safeguarding of billions of dollars invested in lands and in power reservoirs by federal land banks and other banks, insurance companies, other investing organizations, and by individuals and the federal government.

11 Protection to investments of railroads in lines serving farming communities subject to impoverishing erosion.

12 The development of an almost ideal plan for employment, along with a method for the profitable investment of public funds on a long-time basis, with all plans prepared in advance.

Taken in its entirety, an adequate program of erosion control will protect the nation from a menace to its future, equally as threatening and potentially as destructive as an invasion by an enemy army or visitation by almost any conceivable series of natural or economic catastrophes.

* * * *

Obviously, the job immediately ahead is going to be so difficult that for maximum results we may as well decide now that we shall have to work very earnestly together, not merely with agreeably worded intentions, but determinedly and persistently, and upon a basis of sympathetic understanding and helpful association. There is room and great need for the services of all of us who know anything about controlling or preventing erosion, whatever our specialty may be. From the patriotic point of view, it seems clear enough that at all times we should strive to keep uppermost in our minds the accomplishment of an effective job . . . one as nearly effective as our combined brains and efforts can achieve, and this in the interests first and always of the continuing welfare of the United States. It is not meant that our various groups of specialists should not stand up and in a thorough-going spirit of Americanism and professional pride point to every possible contribution we feel that we can make. We must, nevertheless, coordinate our attack, combine our infantry, cavalry, artillery and engineering, intelligence, transportation and supply services, and rout the enemy. If our infantry fails to attain an objective, let's shell the enemy or dig under or around him.

In the meantime, let's waste little thought on such pointless, obvious facts as the certainty that we shall not be able to effect complete control of erosion—a process that began with the first rain falling upon the earth; rather, let's strive to reduce erosion as nearly as possible to that point where soil builds up from beneath as rapidly as it is removed from the surface. Should we not recognize, all of us, that generally speaking we are not ready in America to build the elaborate walls that have been successfully used for controlling erosion in various parts of the world, at prodigious labor costs? Everyone understands that we can not plant our cotton or corn or potatoes or tobacco in the woods or sow our wheat in the undisturbed native sod of the prairies and plains; but I wonder if enough of us have understood what seems to be an unalterable physical fact—namely, that we can not continue to cultivate highly erosive, steep slopes or various types of incoherent soils within

the semiarid regions and at the same time save the land from the ravages of water or wind. Why not recognize these limitations as essential to any successful campaign against erosion, and, accordingly, recommend the retirement of such vulnerable areas to those wise methods of land use employed by nature in giving stability to the landscape . . . that is, turn them to grass or shrubs or trees? We all know there is no serious problem of erosion under a dense cover of such plants, and having learned this much from the age-old pages of Mother Nature, is there any conceivable objection to our profiting by the wisdom? We do not know all that we should as to what degree of slope the practice of annual plowing should be displaced by the practice of planting permanent grass or forest on numerous widely different soils; but let's lose no more time in deciding these things, along with many other uncertainties pertaining to correct use of the land. Without further delay, let's determine, for example, at what declivity we should cease the practice of summer fallowing on the steeper slopes of the Palouse wheat belt. Let's determine whether or not we should advocate seeding certain types of Great Plains soil only in listed fields—and if we find the answer to be in the affirmative, let's adjust our farm machinery to meet the requirements of this kind of cultivation.

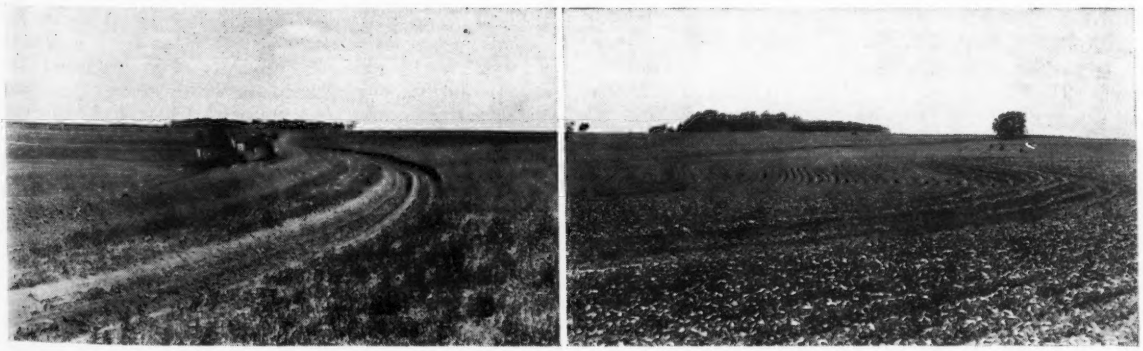
We have already acquired at least a few hints pertaining to these things. We have now, for example, what seems to be adequate evidence to the effect that, if we plant corn continuously on an 8 per cent slope of Shelby loam in north central Missouri, under conditions where the field is perfectly protected from intake of water from above and from the sides, the average annual loss of soil from a cross-section of approximately 73 feet will be at the rate of 60 tons per acre, or at that rate which would result in stripping off the more productive topsoil within about 20 years. And we have learned that along with this loss would go as immediate runoff 27 per cent of all the rainfall and melting snow. Conversely, under a thick stand of alfalfa, grown under the same conditions of soil, slope, rainfall and protection, we have learned that the average annual loss of soil would be at the rate of only about one-fifth of a ton per acre, or at a rate which would result in the stripping off of the topsoil in about 6,000 years. And along with this loss would go as immediate runoff only about 3 per cent of the total precipitation. We have learned also that where a four-year crop rotation is practiced under these same conditions, the average annual loss of soil is at the rate of about 10 tons an acre; and that where ground is kept bare of all vegetation soil loss is at the annual rate of about 112 tons an acre. How much greater these losses would be without protection from the upper part of the field has not been determined.

Should not these available facts, together with many others of similar nature, and many more yet to be acquired, enter into our planning for better land use and for better soil conservation? It seems to me they should, especially when we consider such things as the loss of as much as 500 tons of soil per acre by a single rain falling on a steep cultivated orchard near Santa Paula, California, in 1934.

What little I have had to say about the economic aspects of the erosion problem are not to be construed as carrying any thought of minimizing the importance of this phase of the problem. There is no getting around the fact that, if in order to control erosion we should find it necessary, for instance, to take out of cultivation the entire area of a farm, the operator of that particular farm might find himself faced with a grave economic problem, especially if his soil should not be well suited to grass or other thick-growing, erosion-resistant crops, such as would favor the establishment of a profitable livestock industry. Another interesting illustration in this general connection is furnished in the case of certain western bean-producing districts, where the soil is admirably adapted to beans but poorly adapted to other crops. Here much of the land erodes rapidly down to a tough, sodium-charged clay subsoil that is essentially sterile. Nevertheless, a man conceivably can buy a farm in such a region, pay for it out of his bean crops, make a substantial profit by the time the topsoil is stripped off to worthless subsoil, abandon the farm, and go into some other business with the gains from his soil-destroying enterprise. If it should be proposed to him to quit bean farming and go into the livestock business in order to control the disastrous washing of his land, such a request actually would amount to an invitation to give up a profitable type of farming for one of a much lower income-producing capacity, since these soils are at best only mediocre grass lands. Thus, to the bean grower, the destruction of the land might be of little personal concern, in this country where we have not yet learned to love the land in any sense comparable to European farmers; but from the standpoint of the state and nation, such destructive farming would constitute an economic procedure of grave public concern.

* * * *

In order to carry through an adequate job we must have the cooperation, not only of farmers and landowners, of businessmen and the press, but especially must we have earnest, creative cooperation from organizations such as the American Society of Agricultural Engineers. Apparently we have extended into a new era of better land use in this country. Completion of the job in the greater interest of the nation will surely call for the best brains of the country. There will be a heavy tax on our available agricultural engineers, as well as on the lists of other specialists. May I not urge that in this stupendous undertaking we all work as allies?



(Left) This view shows the constructing of a terrace with heavy equipment. (Right) Strips of oats between terraces. Strips of close growing vegetation planted along the contour also reduce runoff and soil loss

Terrace Outlets[1]

By W. D. Ellison[2]

THE OUTLET channel is a critical section of the efficient terrace system; it is a foundation supporting the project. Where erosion is active in the outlet ditch, it will eventually undermine the entire control structure. If the outlet cuts rapidly, and to considerable depth, overfall erosion at the terrace ends will cause a gully to extend up each terrace channel. If erosion in the outlets is slow, terrace channels are gradually lowered at the outlet ends, their grades become excessive, and the topsoil is carried from the field along the terrace channels. Outlet grades must be fixed before terrace grades can be controlled. Countless fields have been gullied by terrace systems with uncontrolled outlets, and many others have lost their topsoil through terrace channels having excessive grades caused by erosion in the outlet ditches.

Terraces are for the purpose of concentrating flow. They intercept the runoff from a large number of small channels and concentrate it high on the slopes. In the past, attempts have been made to disperse the discharge from terraces by constructing each terrace in the system to discharge at a different point. In isolated cases this has been successful, but as a widespread practice it has been a failure. It has given temporary protection to the terraced area; but it has created a most serious problem at the outlets. Control was effective only until erosion at the outlets undermined the terrace system.

After we have constructed terraces to concentrate the flow, we must prepare specially protected channels to carry it down the slopes. This work will be most successful if natural drainageways are used for outlet channels. A reconnaissance should be made of a large area to determine the best possible outlet locations and the control measures needed to protect the channels. The terrace systems should then be built around these outlets. Each terraced area would then be fitted in as a part of an entire plan for a large drainage unit.

In making the reconnaissance survey and in planning the terracing project, it is not practical to consider the outlet and the terraces separately to the exclusion of each other. Possible terrace plans must be considered at the time best channel sites are selected for investigation. In matching the terrace systems to the topography so as to utilize natural drainageways as outlets, it is often necessary to disregard property lines which seldom conform to watershed or drainage lines. If projects are planned for separate ownerships, without regard to drainage lines, costly and ineffective work will result.

Another consideration of first importance when locating terrace outlet channels is the matter of farm pond development. These outlet channels should be located so as to serve as outlets for small farm ponds. The overflow from the pond can be carried into the outlet channels by a large terrace or diversion ditch. Farm ponds should be planned in connection with terracing systems, and the necessity for arranging the outlet to serve the ponds as well as the terraces cannot be overemphasized.

Often where one side of a slope is to be terraced and the other side of the hill is gullied, diversion ditches can be brought around the hill, diverting water from the heads of gullies into the outlet channel. A well planned terrace outlet properly protected by erosion control measures will serve many purposes.

In making a reconnaissance of a large area to determine the best outlet channel selections to construct the terrace systems around, it is essential that the type of erosion control work necessary for the protection of the channels also be considered.

Our methods of controlling erosion in terrace outlets are of two types: (1) Control with a low-growing perennial grass having an extensive root system, and which provides a permanent vegetal cover; and (2) control with mechanical works. Mechanical works are used where large quantities of water are concentrated and at points where vegetation cannot give sufficient protection.

Disregarding the question of material costs and materials available for the work, there are four variables which enter the problem of selecting proper erosion control measures for the outlet channel. Consideration of these will determine the control measures needed to protect the channel. These four variables are as follows:

1 *Climate.* In semi-arid sections vegetation does not survive long periods of drought with sufficient growth to prevent erosion where considerable water with high velocity is concentrated.

2 *Soil.* A soil low in fertility may not support a vegetal growth sufficient to resist erosion where high velocities occur. A soil that cracks deep in dry weather cannot be protected with vegetation, if channel flow of considerable magnitude and high velocity is concentrated.

3 *Drainage Area.* The size of drainage area determines the quantity of water flowing, and in this way it is a function of the energy expended on the perimeter of the channel.

4 *Slope.* Velocity is a function of slope and hydraulic radius. On steep slopes the hydraulic radius must be reduced by decreasing channel depth and increasing channel width. Large areas on steep slopes require excessive channel widths to maintain low velocities for vegetative control.

In designing channels for vegetative control the velocity must be kept within limits that will not be harmful to the vegetal cover. Permissible velocities will vary widely, these being a function of the vegetation used, the climate, and the soil. Two years ago I prepared a set of curves for designing these channels, which provided for a maximum velocity of 5½ to 6 feet per second in storms of 10-year frequency. These curves are shown in Figs. 1, 2, and 3. Since these curves were prepared, I have had numerous reports on projects and have observed results that convince me these are maximum permissible velocities, where climate and soil conditions are favorable, and a good cover of vegetation is established. Where climate and soil conditions will not support a dense vegetal growth, the width-depth relationship (the hydraulic radius) should be altered to further reduce the velocity.

In areas where climate and soil are favorable for supporting a good vegetal growth in the channels, the selection as between vegetative and mechanical control measures will depend on the sizes of fields and locations available for

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[1]Paper presented at a session of the Soil and Water Conservation Division of the American Society of Agricultural Engineers during the 29th annual meeting of the Society at Athens, Georgia, June 1935.

[2]Supervising engineer (ECW), Soil Conservation Service, U. S. Department of Agriculture. Mem. ASAE.

outlets. In those areas where slopes are short and farms and fields are small, vegetative control has its greatest application. Where slopes are long, land ownerships and fields are large, mechanical measures are most applicable.

The question of how large an area can be terraced into a channel protected with vegetation often comes up for discussion. This question is actually equivalent to asking How long will it take to stop a train going down hill? Without reference to a definite location where vegetation available, climate, soil, and slope are known, a reasonable answer cannot be given as to the acreage the channel will serve.

In the past, most of our channels for vegetative control

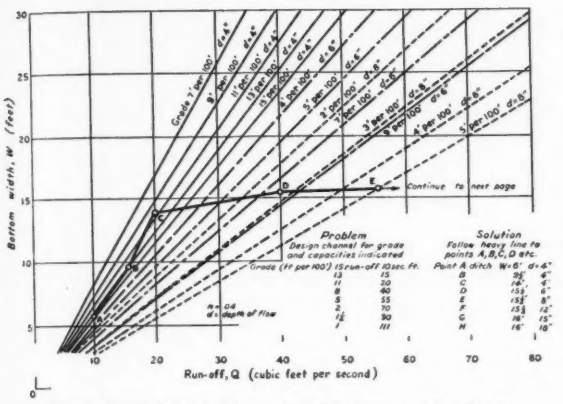

Bottom width, W (feet)
Run-off, Q (cubic feet per second)
Problem
Design channel for grade and capacities indicated
Solution
Follow heavy line to points A, B, C, D etc.
Continue to next page
n = .04
d = depth of flow

Fig. 1 Curves for the design of shallow terrace outlet ditches

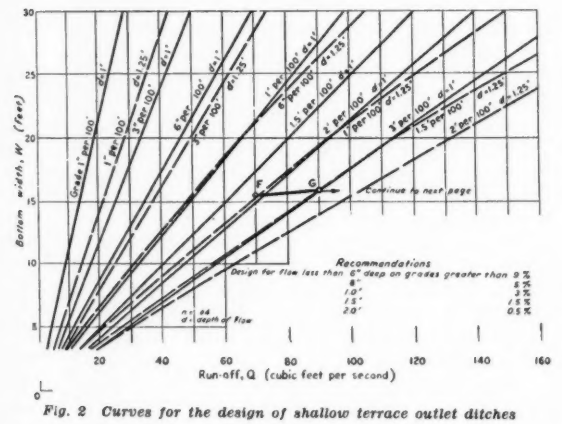

Bottom width, W (feet)
Run-off, Q (cubic feet per second)
Recommendations
Design for flow less than 6" deep on grades greater than 0.5%
Continue to next page
n = .04
d = depth of flow

Fig. 2 Curves for the design of shallow terrace outlet ditches

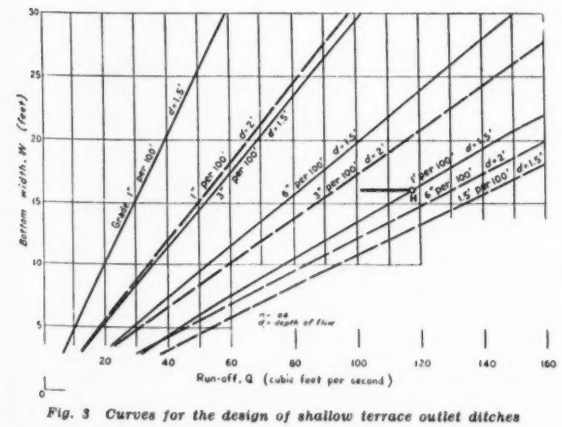


Fig. 3 Curves for the design of shallow terrace outlet ditches

have been dug into the soil, spreader boards (small erosion checks) installed, the perimeter seeded or partially sodded, and the terrace water turned in. This practice is questioned. Channels should not be dug. The topsoil should be left undisturbed, except for leveling off where it is uneven. Levees should be constructed to confine the water and create the channel. The channel area should then be seeded, sodded, or planted with stolons, and the terraces permitted to discharge outside the levees until the vegetation is well established. Robbing the bottom of the channel of its topsoil by excavating the ditch is the cause of many failures.

Spreaders (small erosion checks) should be used in this work to keep the flow spread at uniform depth across the channel bottom. Bags of sod or bags of topsoil containing seed, stakes, slabs, creosoted lumber, wire, loose rock, concrete, and various other materials have been used for this purpose. Undoubtedly the most serviceable and the cheapest of these is a concrete spreader 2 to 3 inches thick. In using this, the trench for the concrete can be excavated to the proper width and depth and the concrete poured into the narrow groove. A board can be set in the top of the trench and used as a screed to strike the top of the concrete to a level. This work makes a neat joint between the firm soil and the concrete. It makes it unnecessary to disturb the soil to either side of the installation as is necessary when most other types of checks are used.

We are in need of a small motor-driven excavator that can be wheeled or skidded across the channel to dig a trench in the soil 2 to 3 inches wide and 12 to 20 inches deep. I believe that with an excavator of this type, and using concrete in the trench, we can reduce installation and material costs to a small fraction of present costs for work of this type.

When levees are built to form the outlet ditch, and there is no excavation in the channel bottom, it is necessary to turn terraces down hill slightly as they approach the outlet. This downslope turn is equivalent to digging a channel and running terraces straight. If the outlet is located in a natural draw, as is advisable for all outlet ditches, the terraces in reality will not be curved at the outlet, but will be straightened considerably by dropping down the slope.

In the humid sections, where slopes are very short and farms are small, vegetation and a few spreaders in the channel now seems the best outlet protection. In a number of these ditches, dams will be needed to protect an overfall at the lower end of the channel. In other areas mechanical works will need be used quite extensively to supplement vegetation.

Where check dam control is needed, the best type of structure to build is one of simple design, with straight lines. The three critical elements of the dam are the notch, the apron, and the cut-off walls to prevent excessive seepage.

In designing the notch we use Mr. C. E. Ramser's recommendations on quantities of runoff.

In the aprons of dams, concrete should be used in preference to masonry. In most instances a 4-inch reinforced concrete apron is less costly and more lasting than an 8-inch masonry apron.

Trenches for all cut-off walls should be excavated to the exact thickness of the wall and the concrete poured into the excavation.

Where rock is available the best type of construction is a concrete apron and concrete headwall extensions, with masonry used for headwalls and wingwalls. All of the concrete can be poured without forms. This type of construction requires no form lumber and is very simple to build. On average work it requires about 1½ to 2 sacks of cement per acre of terraced land, and 20 to 40 man-hours

of camp labor per acre of terraced land draining into the outlet. Where no rock is available and concrete structures must be used, the man-hours per acre is slightly reduced (usually 18 to 35) and the cement averages 2 to 4 sacks per acre.

Fig. 4 shows the type of structure that seems most practical. In using masonry headwalls it is desirable, when staking, to set the "bluetop" about 3 inches below terrace channel grade, as an assurance that the crest will not be finished at an elevation above the terrace grade. The headwall extensions are carried to a height necessary to reach the top of an 18-inch terrace. This is done in all cases as the height of these walls will serve as a ridge-height indicator to farmers, encouraging them to maintain a good height of ridge section.

We have experimented with dams which provide for the terrace channel to enter at an elevation above the bottom of the outlet channel. This structure has a small retaining wall extending upstream from each side of the notch. These walls protect an overfall into the outlet ditch and permit constructing a much narrower, deeper outlet channel. The narrower apron required in this structure saves some material, but the practice is not recommended. It requires much more excavation, and deeper excavations into the subsoil which is most difficult to move. In most areas material costs are a very small part of the job. This is particularly true where supplies of sand and gravel are found locally.

On many projects only one dam is used for each terrace interval. Structures are of such elevation as to leave a grade of 0.25 per cent between the crest of each dam and the bottom of the apron slab of the next dam upstream. This results in a very small grade where structures are widely separated, and larger grades where they are close together.

Where the slope of the land is steep, requiring large vertical terrace intervals, it is often desirable to use two dams for each terrace interval, locating one on the terrace line and the other midway between terraces. A tight, firm subsoil may also be good reason for adopting this practice. By using two low structures much difficult and costly excavation in the subsoil is avoided. When using a structure midway between terraces, it is necessary to use either levees or spur terraces to direct the flow through the intermediate structure.

Where the outlet channel is in a draw, considerable excavation can be saved by moving the structures down hill. This move makes increased terrace height at the outlet end, and the move should not exceed one foot in elevation. Not only does this move reduce excavation, but it also makes straighter terrace lines. The normal contour turns in an uphill direction when crossing a draw, and by building the crest of the dam one foot above the ground considerable turn can be taken out of terrace ridges.

Outlet ditches protected with structures of permanent materials require little or no maintenance. In designing a project of this type it is possible to match the terrace system to the topography because large quantities of flow can be concentrated in one outlet channel. The larger the terraced acreage draining into each outlet, the less the cost per acre for dams. We have found it quite costly to use check dam protection in channels serving less than about 40 acres. The larger the project the less the cost per acre.

There are two principal reasons for this area-cost relationship which gives reduced unit costs on larger areas. First, the unit runoff decreases with increases in area; consequently the material and labor per acre for structures is reduced. Second, the materials and labor that go into wingwalls and headwall extensions are not a function of the drainage area, but are influenced by structure height only. The material and labor used in these walls of dams serving 10 to 20 acres would do the job *(Continued on page 305)*

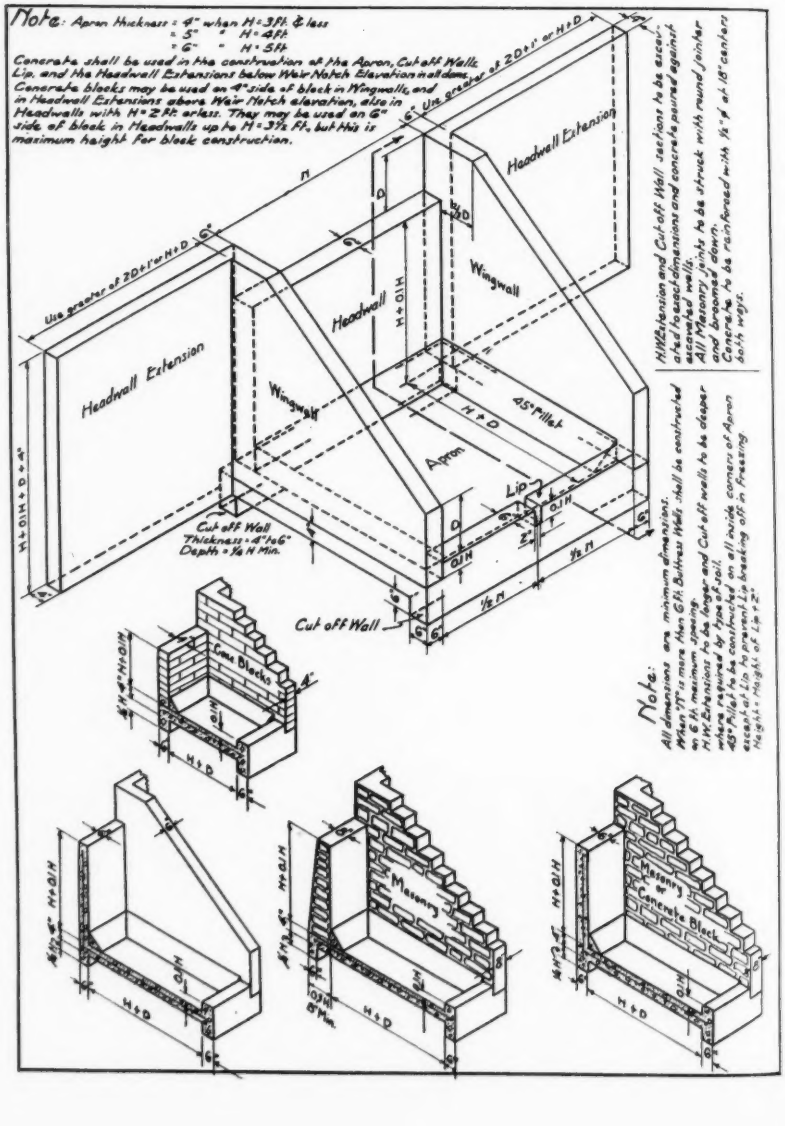
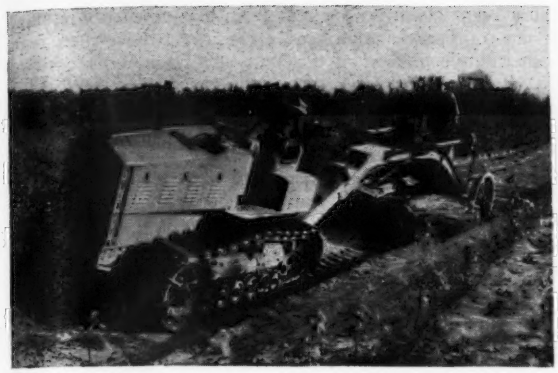

Note: Apron Thickness = 4" when H = 3Ft. & less
= 5" " H = 4Ft
= 6" " H = 5Ft
Concrete shall be used in the construction of the Apron, Cut off Walls Lip, and the Headwall Extensions below Weir Notch Elevation in all dams. Concrete blocks may be used on 4" side of block in Wingwalls, and in Headwall Extensions above Weir Notch elevation, also in Headwalls with H = 2 Ft. or less. They may be used on 6" side of block in Headwalls up to H = 3½ Ft., but this is maximum height for block construction.
Use greater of 2D+1' or H+D
Headwall Extension
Wingwall
Headwall
H+D+H
45° Fillet
Apron
Lip
Cut off Wall
Thickness = 4" to 6"
Depth = ½ H Min.
Cut off Wall
Cone Blocks
Masonry
Masonry or Concrete Block
H+D
All dimensions are minimum dimensions. When "H" is more than 6 Ft. Buttress Walls shall be constructed on 6 Ft. maximum spacing.
H.W. Extensions to be keyed and Cut off walls to be deeper where required by type of soil. All inside corners of Apron except Lip to be rounded by floating off in Forming
Height of Lip = 2"

Fig. 4 Details of a standard small check dam



Building terraces with Cletrac Diesel tractor and Austin-Western terracer

The SCS Erosion Control Program[1]

By T. B. Chambers[2]

THE SOIL Conservation Service of the U. S. Department of Agriculture recognizes the fact that erosion control, to be effective, permanent, and economically feasible, involves more than the use of vegetative and engineering methods. It involves also general land-use planning, proper crop rotations, contour cultivation, controlled livestock grazing, and the application of other sound farm management practices. Visual evidence, as well as results from federal soil erosion experiment stations, teaches us that no one method is entirely successful. Strip cropping has been practiced for years on steep slopes in certain sections of the country. In other sections terracing has been common for generations. While both of these methods are effective, neither is an entire cure within itself. In addition, crop rotation, contour cultivation, leguminous cover crops, and other practices that will add humous and nitrogen to the soil, must be used. Certain steep or highly erosive lands must be retired from cultivation and placed in permanent pastures or forests. Often the condition of the soil itself indicates the particular treatment that will prove most effective, and at the same time allow the production of crops on which the farmer is dependent for a livelihood. After all, our recommendations and practices must be practical. If we are to expect cooperation and continued use of methods being demonstrated, we must leave the farmer something beside a reduced income as repayment for his labor.

DEMONSTRATIONAL PROJECTS. In order to demonstrate effective, practical methods of erosion control, the Soil Conservation Service has established forty demonstrational projects. Of these forty projects, two are located in New York and New Jersey and are strictly experimental; three are located on public lands in the semi-arid grazing sections of Arizona and New Mexico; three are wind erosion projects located, respectively, in Texas, Colorado, and South Dakota, and the remainder are watershed projects located in various farming regions. This paper will deal primarily with the methods and treatments ordinarily used on the latter class of projects.

On these projects have been brought together groups of specialists who work out a unified, coordinated program. These specialists represent the branches of engineering, soils, agronomy, forestry, range management, and wild-life management. They are used in any combination, according to the particular farming practices of the region.

In order that no misconception exist and to acquaint you with our aims and purposes on the watershed projects, it would seem proper to explain that on these projects we are attempting to demonstrate correlated principles of erosion control on contiguous farms within the watershed boundaries. The fundamental principles are those recommended by the various technical specialists. They are demonstrational in that they actually place in use visual methods of control that are recognized as fundamental. They are experimental in that an opportunity is presented to prove or disprove their practical and economic worth. These projects were not established as work relief agencies, as is sometimes thought. Neither is the primary purpose to furnish the farmer some immediate pecuniary assistance. We want to demonstrate to him and other farmers operating on similar soils and under similar conditions the methods of erosion control that can be practically adopted by all.

It is true that the projects are relief projects in a certain sense—the sense that CCC labor, a relief agency, is used where possible and also in the sense that when it is necessary to employ unskilled labor, individuals are chosen from county relief rolls and paid established relief rates. All individual operators of farms where erosion-control work is done, are required to cooperate by furnishing labor and materials to the extent of their ability.

PROCEDURE. Briefly, this is the procedure on the demonstrational areas. The Service prepares a map showing the contemplated field work. On this map the chief soil specialist indicates certain pertinent facts regarding the particular plot of land under consideration. He indicates (1) those areas recommended to be taken out of cultivation because of excessive susceptibility to erosion, because of excessively steep slopes, or because of the inherent character of the soil; (2) strip-cropping, contour cultivation, terracing, etc.; and (3) those areas, if any, which may be recommended for thick-growing crops or pasture only. All of these recommendations are determined by a thorough,

[1]A paper presented at a session of the Soil and Water Conservation Division of the American Society of Agricultural Engineers during the 29th annual meeting of the Society at Athens, Georgia, June 1935.

[2]Assistant chief engineer, Soil Conservation Service, U. S. Department of Agriculture.

careful survey of the land, and agreed to by the interested specialists.

Then the federal government contracts with the farmer to put erosion-control measures into operation on the land. Copies of the work maps are given to the engineers, agronomist, and farm management specialists. Usually there are two engineers, one assigned to gully-control work and one assigned to terrace construction.

The extent of terracing, obviously, depends upon the slope of the fields and character of the soils, as well as the farming practices in use.

Gully control work is held to an effective minimum. Diversion of headwaters, brush dams to enable seeding and planting both within and around the sides of the gully, will be all that is necessary in most cases for stabilization.

The farm management specialist can often rearrange fences and fields in such a way that better advantage can be taken of the topographic condition of the land.

The agronomist plans the cropping system to include strips of thick-growing crops across the slopes of the contour where tilled crops are grown. He can designate thick, soil-saving crops for those areas too steep for cultivated crops, and he can plan rotations which will build up the land and protect the soil from erosion. He can also plan the arrangement of crops so that no one cultivated crop covers an entire long slope.

A forester handles the work of reforesting areas that need such treatment.

RELATION OF ENGINEERS TO PROGRAM. The relation of engineers to the program, however, is probably of more interest to this group than the strictly vegetative and land-use phases. The engineer occupies an important place on all the demonstrational projects. His interest is broad, and in addition to designing and constructing mechanical structures, surveying, mapping, and contour work, his activities must at all times be correlated with those of the other specialists.

Terracing is one of the most important control measures of the program. It is recognized as the foundation of a complete erosion control program wherever clean cultivated row crops are grown. It is also recognized that terracing is limited to certain soil types and slopes. Beyond certain slopes, it is impossible to construct effective, economical terraces. It is also impossible on the same slopes to successfully control erosion by strips, crops, or rotation, and the only alternative is to retire the land to pasture or trees. Data from the federal soil erosion experiment stations show that the soil loss from properly terraced land is reduced on an average about 80 per cent from that ordinarily resulting from comparable unterraced areas. We believe there is no other single method of erosion control equally as effective.

Practically all types of terracing equipment are used in the projects of the Soil Conservation Service. By far the most widely used is the track type tractor and blade grader. This unit has proven most economical under all conditions of soil slope, topography, and field size. In the South where small fields and rough slopes predominate, the two-wheel grader is in general use, while in the central and southwest sections, with larger fields and smoother slopes, the four-wheeled machine is in favor. On one or two of our projects terraces are constructed with elevating graders, but because of additional blade work necessary to properly shape the channel and ridge, they have not proven more economical than blade graders. Horse-drawn blades and fresnoes are also used under certain conditions but result in a much more expensive terrace.

The policy of the engineering department of the Soil Conservation Service at all times has been to recommend heavy tractor-drawn equipment for use in construction of terraces on demonstrational projects. This policy was dictated by the economical performance of heavy equipment.

Thousands of cases can be observed in the Piedmont section where small, poorly-constructed farm terraces have resulted in doing more harm than good. The fault has not always been with those designing and advocating terraces, but has been due primarily to the excessive cost of construction with the light equipment. The farmer found that it was such a laborious and expensive job to construct terraces with his ineffective horse-drawn equipment, he discontinued work before the ridges were of ample size or else constructed his terraces along excessive grades. Either method resulted in the concentration of water at such erosive velocities that gullies were produced in the very fields he was trying to save. Why not, then, on demonstrational projects. demonstrate an economical method of construction, and at the same time realize that the effective construction of terraces is not an individual proposition, but should be carried out by cooperative organizations who purchase the equipment and rent it to individual members. Often the cost of renting this equipment is no more than the first cost in purchasing small equipment with which to do the job.

The need for terracing and other erosion preventive measures is urgent. There is more work than all present agencies can do in a reasonable time. Thousands of acres of good lands are being destroyed yearly and other thousands so depleted in fertility that they can not be economi-

(Left) Gully control, in which a series of low-wired check dams have been installed in the head of a large gully. Grass and trees have been planted to control the gully after the temporary type dams have failed. (Right) A masonry dam constructed in the head of a large gully to prevent its extension across a cultivated field. No vegetation is needed with permanent dams of this type.

cally farmed. Unless terracing and related control measures are put into operation at a much faster rate, additional millions of acres of land will be irreparably damaged. As an example, one state that does a large amount of terracing through its extension service reported a total of 80,000 acres terraced last year. While this is a creditable showing for those engaged in the work under present conditions, it is entirely inadequate when we realize that in this same state, conservative estimates show that 150,000 acres in each of 50 counties are in immediate need of terracing. In other words, the entire efforts of the state resulted in terracing slightly over half of one county. Slightly over one per cent of all lands needing terracing was completed in a year. If the government would make loans to individuals to defray the cost of terrace construction and other erosion control features, it is probable that the job might be completed in a reasonable length of time. Such loans would appear to be of equal importance with seed and other crop loans.

Gully control work is an important part of the engineer's work on several of the demonstrational areas. Working on gullies, however, is to some extent an unsatisfactory occupation; it is like treating an ulcer without doing something for the underlying causes that produce it. Badly gullied land has generally lost its commercial value and ordinarily planting to vines, trees, shrubs, or other controlling vegetation is the only protective measure justified. Instances are found where gullies encroach upon valuable lands and in such cases mechanical control measures are in order. Such measures may consist of a head dam of permanent construction, a diversion channel to conduct the water away from the gully head, or a series of temporary check dams to assist and protect a stabilizing growth of vegetation. Gully banks are sometimes sloped to an angle of repose so that a controlling vegetation may be more quickly established. Sloping is done by hand, plow, dynamite, or by tractor equipped with bulldozers or trailbuilders.

A summary of the engineering work completed on the demonstrational projects June 1, 1935, shows that

1 10,239 miles of terraces covering 129,400 acres have been completed.

2 348,800 acres contracted for new terracing.

3 To serve the terraced fields a total of 1,800,000 linear feet, or 359 miles of terrace outlet channels have been constructed.

4 A total of 266,800 dams have been constructed for gully control, while 18 miles of diversion channels were excavated for the same purpose.

CCC Camps. The allotment of a large number of ECW camps to the Soil Conservation Service, effective July 1, will result in erosion-control work in a large number of areas not on the demonstrational projects. This work on farms near the camps will be based on a coordinated program similar to that now being carried out on the watershed areas. It will be carried on, wherever possible, in cooperation with the agricultural extension service, vocational agricultural teachers, agricultural colleges and other interested agencies; and it is recommended that the county agents, through state directors of extension, be encouraged to organize the farmers in the vicinity of each ECW camp into erosion-control associations. Such associations, with the cooperation of the project manager, would determine priority of work within each camp area, and would designate demonstration farms to receive complete erosion treatment. They would also purchase cooperatively such machinery, seeds, and other supplies necessary to conduct a complete erosion program. The camps, of course, will be held to approved ECW practices, which include terrace outlet, gully work, and other related activities.

Occupational Opportunities of Engineers. A glance at the occupational opportunities offered engineers by expansion of erosion control work would not be out of place at this time. The Soil Conservation Service employs at the present time approximately 276 engineers. Other government and state agencies employ large numbers. The work is in its infancy and the field has scarcely been touched. I have tried to show to some extent the enormous amount of terracing that should be done immediately. There are correspondingly large amounts of strip cropping, gully work, and pasture contouring to be done, all of which requires personnel equipped with engineering training. To some extent we are pioneering in this field of engineering activity. The design, construction, and protection of terrace outlet channels is a new endeavor that has never been undertaken on a large scale before. Of course, only old principles are used, but they are given a new application. Research work in engineering methods of control also offers a large field of opportunity.

Additional places will be open to those working on the adaptation of construction and cultural equipment to erosion control practices. It is probable that a great many changes will be made in cultural equipment to facilitate crossing terraces and to meet the requirements necessary for contour cultivation. Much is to be desired in terracing machines, and it is probable that a much more economical machine will result from research along this line.

I would not overlook the opportunities that may be offered to terracing contractors. There are probably many objections to this method of terracing, but it may be only a matter of time until enterprising individuals will actively enter the field, and a large number of contractors might go a long way toward economically solving the terracing problem for the farms of the country.

Terrace Outlets

(Continued from page 300)

on a 200-acre project. On small projects the material and labor in ends of structures is a large part of the total cost. On large projects it is a very small part of the entire job.

Where a large project is designed, using check dams in the outlet channel, it is not necessary to use dams in the upper portion of the channel which serves the first two to six terraces. This portion of the channel can be treated as a small project using vegetative protection. If the vegetation fails and more structures are necessary, they can be installed later with the lower structures serving as protection to the foundations of dams later built in the upper reaches of the channel.

It is not sound practice to use roadside ditches and oversized gullies as terrace outlet channels. Where a road crosses a hill, the grade is usually lowered by a cut, requiring a structure in each terrace end and additional structures in the roadside ditch to protect it. This is usually a waste of materials and labor. Old gullies as outlets present the same problem. They make it necessary to drop the water at each terrace, and then protect the bottom of the channel with structures.

In the Soil Conservation Service we are now setting up a cost accounting system that will establish the relative costs of various types of channel erosion control work. As soon as these records are available we will know far more about how to best do the job. Channel grades, locations of channels, type of control used, size of terraced project, size and shape of channel selected, and many other factors have a bearing on final costs. We hope to evaluate some of these unknowns in the near future.

Results of Recent Engineering Studies in Soil Erosion Control[1]

By F. O. Bartel[2]

THE CENTRAL Piedmont soil erosion farm of the U. S. Conservation Service at Statesville, North Carolina, was established in May 1930. It was designed to represent, in a general way, the entire southern Piedmont, an area of 51 million acres extending from eastern Pennsylvania into east central Alabama. More particularly it will serve the southern part of Virginia, North and South Carolina, and northern Georgia, in which states climatic as well as soil conditions and farming practices are similar.

The farm is located on a typical Cecil soil. This series constitutes the most widely distributed soils of the Piedmont area. Not only is it found in practically every county, but two types, the Cecil sandy loam and the Cecil clay, together make up approximately two-thirds of the entire Piedmont area. The farm was the final selection after looking over approximately 100 proposed sites, and is believed to be as representative of typical conditions as any that can be found.

In the matter of climate, it is also representative. The annual average temperature is 59 degrees, its elevation ranges from 765 to 975 feet above sea level, and the rainfall averages 50 inches. It lies within the cotton belt, and other crops typical of the section are grown.

Engineering studies now under way at the Statesville farm include investigations of the rates of soil and water losses from terraced and unterraced land; the effect of differences in land slopes and soil conditions upon such losses; the most practical grade, height, spacing, and shape of terraces; the cost of terrace construction, of terrace maintenance, and of cultivating terraced lands; the proper method of laying off crop rows; the economical use and development of farm machinery and other problems relating to terraces and their use. The construction of check dams and soil-saving dams, the control and reclamation of gullied land, the effect of subsoiling eroded soil and the study of moisture losses and crop yields are phases of the engineering studies projected or under way.

RESULTS OF ENGINEERING STUDIES. Perhaps the most fundamental of all of these investigations is the determination of the comparative soil and water losses from unterraced, terraced, and wooded areas.

Standard Parshall flumes with Ramser silt samplers are used to obtain these measurements. The results have been compiled for 1932 and 1933. In considering these a description of the three areas should be kept in mind.

All three plots are of approximately equal area, about 5 to 6 acres. The terraced field has an average slope of 10.2 per cent, while the slope of the unterraced area is only 7.2 per cent. The soils on the two areas are quite similar in character but vary greatly in depth and fertility. The soil of the unterraced field averages about 15 inches in depth as contrasted with a depth of 3 inches on the terraced field. The two fields adjoin, the soil of the unterraced field having been formed largely of material washed down from the terraced field. The difference in fertility is indicated by the 1933 crop yields which were 20.3 bushels of oats per acre from the terraced, and 41.1 bushels per acre from the unterraced field. The flume on the unterraced area was set about 4½ feet above the bottom of a gully that extended down its center. This gully was plowed in just before measurements began, and this reservoir of spongy, unsettled soil undoubtedly absorbed and is perhaps still absorbing much of the rainfall that would otherwise run off.

In spite of these more favorable conditions of soil, slope, and heavier crop cover, the unterraced area lost 8½ times as much soil during 1932 and over ten times as much during 1933 as did the terraced area.

The terraced field contains one uniformly graded terrace having 3 inches fall per 100 feet, 1200 feet long; another similar terrace with a grade of 6 inches in 100 feet, and two variably graded terraces 1500 feet long with grades ranging from 1 to 6 inches in 100 feet. We are no longer recommending over 4 inches fall per 100 feet on terraces.

Not only did the unterraced area lose ten times as much soil, but the total runoff was 48 per cent greater, and the maximum rate of runoff attained was almost five times as much. During August 1933, with both fields in lespedeza, 1¼ inches of rain fell on a saturated soil, causing the almost unbelievable rate of runoff of 4.63 inches per hour from the unterraced field. The greatest rate of runoff for this rain from the terraced field was only 0.62 inch per hour, only 1/11th as great. These are heavy flows from land under a cover crop.

The experiments on the 6-acre wooded area have only been conducted for the one year 1933. The soil loss for the year was only 0.016 ton per acre, which is 1/143 of that from the terraced area, and 1/1450 of that from the unterraced area. The terraced area lost 6.4 times as much water and the unterraced area 9½ times as much.

The wooded area is heavily timbered with a thick stand of pine and hardwoods. A surface layer of litter at least 2 inches thick covers the ground. Conditions for soil and water conservation are ideal, though the slope is steep, averaging 18.6 per cent.

During 1933, seven storms were listed as principal storms, that is, with both high amounts and intensities of rainfall. It is interesting to note that these seven storms were responsible for the entire soil loss from the wooded area, but caused only 90 per cent of the total loss from the terraced area and 83 per cent from the unterraced area. All of these storms occurred during the spring and summer.

The unterraced area (in lespedeza) lost 64 per cent of its year's washoff during three rains (two rains in March and one in May); the wooded area, 50 per cent; and the terraced area 48 per cent of its total for the year. It should be noted that the summer of 1933 was very dry, the rainfall being less than three-fourths the normal amount. Under ordinary conditions more soil is lost in the period from June to September than during any other season.

A peculiarity of rainfall distribution at Statesville and a few South Carolina stations lying to the southwest of Statesville is a minor rainfall peak in March (or February and March) which is not found over the rest of the Piedmont

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[1]Paper presented at a session of the Soil and Water Conservation Division of the American Society of Agricultural Engineers, during the 29th annual meeting of the Society at Athens, Georgia, June 1935.

[2]Agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. Mem. ASAE.

area. These spring rains may be the cause of severe erosion over this district.

EFFECT OF TERRACE GRADE. A second most interesting experiment is that designed to show the proper grade for a terrace. We have two such experiments, one with short terraces on poor sandy soil, and another with long variable grade terraces on a heavier soil.

The short terraces are all 655 feet long, have a 5-foot vertical spacing, and vary in grade from 9 inches in 100 feet to level. Losses from these terraces have been measured since September 1, 1933. Crops have been soybeans broadcast in 1931; wheat and vetch in the winter and spring of 1932 followed by soybeans in rows; oats and lespedeza in 1933.

The terraces showed a consistent variation in both runoff and erosion with increase in grade of the terrace channel. The percentage of runoff to rainfall ranged from 29 to 17 per cent as the grade varied from 9 inches in 100 feet to level. Soil losses are as follows:

TOTAL SOIL LOSSES FROM SHORT TERRACES
(September 1, 1931 to December 31, 1933)

Terrace	Grade	Soil loss, tons per acre	Soil loss, per cent
D2	9 in uniform	19.958	164
D3	6 in uniform	17.507	144
D4	0-6 in variable	12.163	100
D5	2 in uniform	10.291	85
D6	0	3.879	32

In comparing results from this experiment, it should be noted that the watershed slope of D2 averages only 8 per cent as compared with an average of 12.2 per cent for the other terraces.

An exceedingly high rate of runoff was measured from this terrace following a 1-inch rain on August 8, 1932, which fell on saturated ground. The field at this time was in a cultivated stand of young soybeans. Eighty-three per cent of this rain ran off the terrace watershed, bringing with it 1.796 tons of soil per acre.

The above checks with experiments conducted by the author in the vicinity of Raleigh, N. C., which indicated that water losses from terraces having as much fall as 9 inches in 100 feet were as great as from unterraced plots in the same crop.

As compared with the variable grade terrace, the terrace with 6 inches fall in 100 feet lost 44 per cent more soil; and that with 9 inches in 100 feet, 64 per cent more soil. In checking the terraces at the end of the crop year, it was noticed that the channel of the terrace with 9 inches fall in 100 feet was eroding slightly, that with 6 inches fall had neither eroded nor filled in, while the channels of the remainder had all silted in appreciably.

Considering these results, and from observation of our terraces as a whole, we believe that about 4 inches fall in 100 feet should usually be considered a maximum for good terracing practice, and that variable graded terraces are preferable to uniform grade terraces.

Terrace banks are worked down with every cultivated crop, and need occasional reworking to maintain their height. The logical place to secure material for this building up is from the terrace channel.

The level terrace and the terrace with 2 inches fall in 100 feet silted in spots and dammed water in the channel. In this particular field the ponded water did not harm crops or hinder cropping operations appreciably, but did affect the records, as water was held back which would have run off had the grades been uniform. It was found that the runoff always increased immediately after regrading the terrace channels to theoretic grade.

The three long terraces, on the terrace fall experiment, include one variable grade terrace 1500 feet long with grades varying from 1 inch in 100 feet to 6 inches in 100 feet; one uniform grade terrace 1200 feet long having 3 inches fall per 100 feet; and another similar terrace with 6 inches fall in 100 feet.

As compared with the long variable grade terrace, the uniform grade terrace with 3 inches fall in 100 feet gave practically the same runoff, and 16 per cent soil loss. The 6-inch terrace, however, showed 50 per cent greater runoff and 53 per cent greater soil loss. The maximum rate of runoff was just under 1 inch per hour from each terrace.

TERRACE SPACING. There are four experiments on terrace spacing at the Statesville station, namely

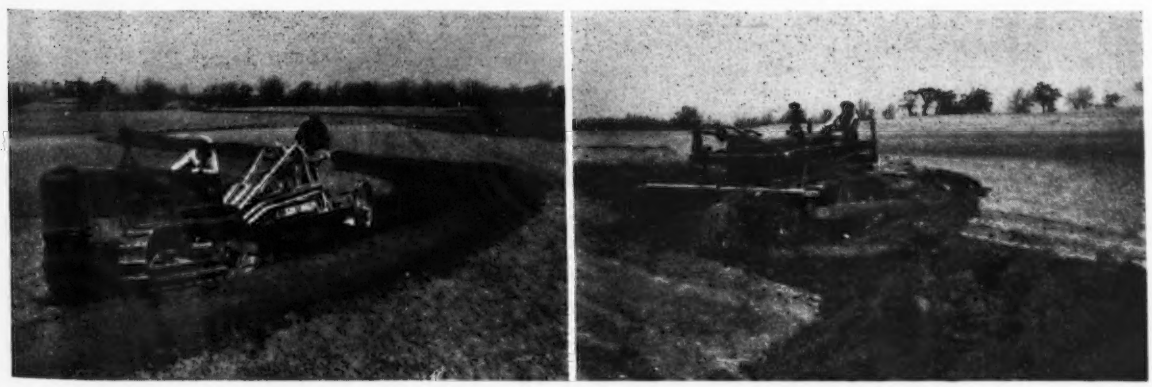
1 Long variable grade terraces on steep slopes
2 Short uniform grade terraces on steep slopes
3 Short uniform grade terraces on moderate slopes
4 Level terraces on steep slopes.

There is probably more difference of opinion on terrace spacing than on any other question relating to terracing. Hence, these experiments will be described in some detail.

Results from these spacing experiments have not been consistent; in some cases the wider spacing has shown greater soil loss; in others, less.

Considering the first of these experiments, namely, long variable grade terraces, two terraces are included both 1500 feet long with grades varying from 1 inch in 100 feet to 6 inches in 100 feet. The spacings are 4 and 6 feet, respectively.

The results show that 12 per cent of the rainfall was



(Left) Building terraces with McCormick-Deering Diesel tractor and Adams terracer. (Right) McCormick-Deering Diesel tractor equipped with Continental trailbuilder for filling in low places in terraces

lost from the former compared with 18 per cent from the latter. The terrace with the 6-foot spacing had 57 per cent greater soil loss as well; and a maximum runoff of 1.13 inches per hour as compared with 0.98 inches per hour from the 4-foot spacing.

Examination of the profiles of the terrace channels taken at the end of the period, however, show that the terrace with 6-foot vertical interval is almost exactly in agreement with the theoretic profile, but that the other is irregular with basins about midway and toward the upper end. It is believed that these miniature detention reservoirs are accountable for the large difference in results rather than the spacing.

For several of the experimental fields which were in cultivated crops during 1932 and in cover crops in 1933, the soil losses were larger with the cover crop (lespedeza) than with the row crop (soybeans in 28-inch rows). This was true despite rainfall 10 per cent above normal in 1932 and 33 per cent below normal in 1933.

The explanation lies in rainfall distribution. In 1933, the year of low rainfall, extremely heavy spring rains fell on the freshly prepared seedbed just after the lespedeza had been planted, causing much soil loss and washing away much of the seed. A dry, early summer followed during which the crop suffered from drought. During August, heavy rains occurred with a poor cover on the land causing further heavy losses. The year 1933, then, in spite of its having only two-thirds normal precipitation, was a year of heavy soil losses.

The short terraces on steep land are all 700 feet long and and have uniform grades of 3 inches in 100 feet. Three terraces are being studied with vertical spacings of 3, 5, and 7 feet. Crops were corn in 1933 and barley mixed with lespedeza during 1932. Conditions were quite favorable for accurate results from this experiment, except that the channel of the terrace with the 7-foot interval was somewhat more irregular than the other two and may possibly have reduced its losses slightly.

The percentage of runoff to rainfall for the period showed a difference of only 1 per cent between these terraces. Soil losses, however, were consistently less from the terrace having the intermediate (5-foot) spacing than from the other two. On the basis of results from this terrace, that with the 3-foot vertical interval showed 26 per cent greater soil loss, while that with the 7-foot spacing showed only 16 per cent more. These differences were found for erosion under corn; under a cover crop soil losses as well as runoff were closely equal from each terrace.

The years in which cover and row crops were grown were reversed in this field from most of the rest of the farm. During 1933, the year that the other experimental fields lost, on the average, twice as much soil from a cover crop of lespedeza, this field (in corn) lost only three times as much soil as it did the year before under a very good stand of lespedeza.

The third spacing experiment includes uniform grade terraces on a moderate slope. These all have grades of 3 inches in 100 feet, are 550 feet long, and are spaced 2, 4, and 6 feet apart.

Of these terraces, that with the 2-foot spacing lost the most water—about 25 per cent more than the two with the wider spacing. Soil losses followed those recorded for the preceding experiment in being consistently less for the intermediate (4-foot) spacing. The terrace with the 2-foot vertical interval lost 35 per cent more soil; that with the 6-foot spacing, 48 per cent more.

The eleven principal rains during this period (all occurring during May to September and constituting 12 per cent of the rains causing runoff) caused two-thirds of the total soil loss. The maximum rates of runoff from the terraces spaced at 2, 4, and 6 feet were 1.61, 1.49, and 1.75 inches per hour, respectively.

The fourth spacing experiment was with level terraces on steep land spaced 4 and 5 feet apart. These experiments did not yield satisfactory results because of silting and consequent ponding in the terrace channel. They were complicated likewise by a variation in the slope of the land. The experiments were discontinued after the first year. One year's results, however, show about 30 per cent higher soil loss from the 5-foot spacing than from the 4-foot spacing.

Reviewing the four experiments, the conclusion is that other factors, such as uneven silting and ponding in the terrace channel, uneven topography, etc., may have greater influence on the amount of erosion and runoff than the spacing. As the interterrace areas become more stabilized, these intangibles will exert less influence, and the direct effect of variation in spacing can be better measured. Judging from results obtained to date, it would seem that 5 to 7-foot spacings on slopes up to 12 per cent, especially on short terraces, would not result in excessive soil losses.

A new terrace has been added to the experiment with the 3, 5, and 7-foot spacing on which measuring equipment will be placed as soon as funds are available. The spacing on this new terrace is 9 feet. It is felt that it will add materially to the value of the project.

EFFECT OF SLOPE OF LAND. With respect to effect of runoff and erosion from terraced areas, only one experiment is being carried out at present. This is on short level terraces with 5-foot vertical interval on 13 and 17 per cent slopes. The erosion was found to be 11 per cent greater on the steeper slope. Total runoff and maximum rates of runoff were likewise slightly increased by the greater slope.

LENGTH OF TERRACES. A few years ago 1500 feet was considered the maximum allowable length for a variable grade terrace with the customary spacing and height. For a uniform grade terrace with 6 inches fall per 100 feet a length greater than 1200 feet was not recommended.

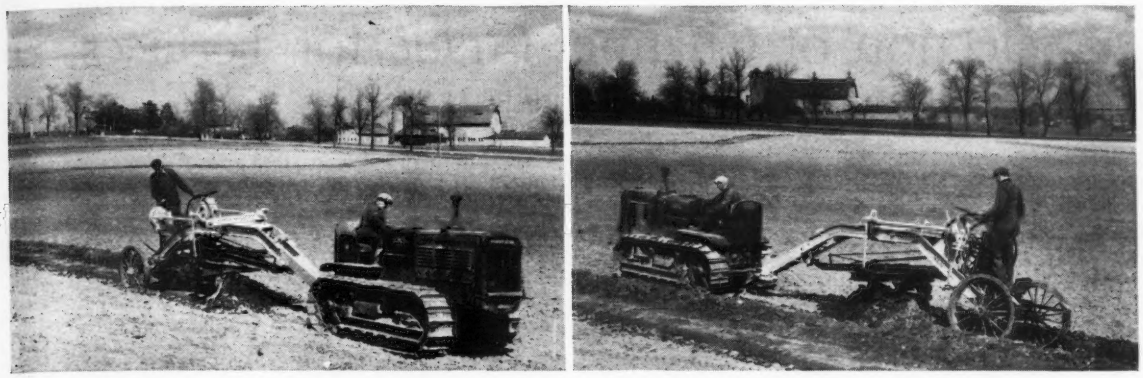
We have three terraces on the Statesville farm carrying the water one way for 1400, 1700, and 2000 feet with a uniform grade of only 3 inches in 100 feet which have given entire satisfaction since their construction in the spring of 1931. Evidently we can build considerably longer terraces than was formerly thought possible.

LEVEL TERRACES. We have conducted several experiments with level terraces both ring type with closed ends and with open ends. In this locality level terraces on land of rough topography are not usually very satisfactory due to formation of deltas in the channels below points where water concentrates and washes soil from the interterrace area. Water held in the channel by these deltas causes the drowning of crops and hinders farming operations. A tractor or other heavy farm implement may throw up a ridge across the channel when the soil is soft, thus ponding back water. On ring terraces, or those with closed ends, standing water is often found for as long as a week after heavy rains. On level terraces with open ends up to 300 or 400 feet long such pockets are usually not troublesome, due to erosion at the ends giving some fall to the terrace.

Another practical disadvantage of level terraces is the increased expense of building and maintaining them, more careful grading being necessary.

CROSS SECTION OF TERRACES. A careful analysis has been made of size and shape of the completed terraces from some 400 cross sections.

The average terrace on the Statesville farm is 1.60 feet high and 24.7 feet wide, is built on land having a 9.9 per cent slope, and has a water channel capacity of 14.2 cubic



Two views of building terraces with McCormick-Deering Diesel tractor and Austin-Western terracer

feet per foot of length. An average of 27 cubic yards of soil per 100 feet of length must be moved in building this terrace. The average slope from the crown to the toe of the bank is 31.4 per cent. The bottom of the water channel and the crown falls between the quarter and third points of the width. The height of the terraces increases as the slope increases, varying from 0.98 feet on a 3½ per cent slope to 1.56 feet on a 16 per cent slope. The width, however, decreases from 29 to 22 feet as the slope changes from 3½ to 16 per cent. The slope of the lower terrace bank increases from 15 to 43 per cent as the slope increases between these limits. There is a practically constant relationship between the height of the terrace and the horizontal distance from the crown to the lower toe, this distance being closely five times the height.

COST OF TERRACE CONSTRUCTION. The cost of terrace construction depends upon such factors as the skill and experience of the tractor operators, the type and size of the machinery, the power available, the steepness of the slope, the character of the soil and cover, the grade of terrace channel, the amount of straightening done, and the number of gullies and other topographical irregularities in the field. The terrace construction on the Statesville farm was rushed, due to the need of getting experimental work started, and the cost figures derived probably represent maximum rather than normal figures. Due to the necessity for speedy construction, little experimentation was carried on in various methods of construction, but the terraces were all built by what seemed the speediest and most economical method, that is, moving most of the soil from the upper side. That is, all grader work was done on the upper side only, though where the plow was used both sides were plowed. Only wheel type tractors and small terracing machines were available, and the soil was so thin and hard that it was usually necessary to loosen it by plowing ahead of the terracing grader. The terraces averaged from 20 to 27 feet in width and ranged from 9 to 22 inches in height in the different fields. The terrace lines were straightened more than customarily on such irregular land to make the experimental records of soil and water losses more representative of typical conditions.

The average number of tractor rounds of grader or of plow and grader combined was 55 per terrace. The cost varied little with the different types of equipment used, which consisted of various combinations of John Deere 15-27 tractors; 10-20 Farmall tractor; Texas, Corsicana, and Martin terracers, and a rigid-hitch, Taylor-Farmall two-disk plow. There was also no appreciable difference in the cost when the land was plowed ahead of the grader and when the grader did its own plowing.

The average cost per cubic yard of material moved was 4.13 cents for grader work exclusive of System A.

The terraces were built in three workings with a period of settlement between each working. An analysis shows that in the final working the heights of the terraces were in all cases materially reduced, as was also the number of cubic yards (with reference to the original ground surface) and that the cost per cubic yard was increased two to three times compared with figures from the second working. The purpose of this third working was to give bulk and solidity to the terrace bank. From this it may be deduced that completing the terrace in one operation would greatly reduce the cost of construction. This would, however, require the employment of heavier, more powerful machinery than was available.

The cost per 100 feet of terrace construction excluding the A-system averaged $1.43 for grader work, ranging from $0.85 for the B-system to $1.58 for the D-system. Per acre grader costs averaged $10.28 exclusive of the A-system, in which the terraces were literally carved out of the steep hillside, and the ground was so hard that it had to be loosened by a road scarifier drawn by two John Deere tractors in tandem. There were also about 50 per cent more terraces constructed in this system than necessary. Grader work on the A-system of terraces cost $25.31 per acre.

Labor costs, figured at 22½ cents per hour, constituted 54 per cent of the total.

Scraper work to fill in low places in the terrace banks and to cut down high spots on the terrace channel increased the cost by 73 per cent. The amount of scraper work was especially large on the Statesville farm due to the large number of gullies crossed, the variation in slope in different parts of the fields, the straightening of the terraces to do away with excess variations in curvature which would effect experimental results, and the tendency of the wheel type tractors used to slip down hill, especially on curves, pulling down the ridge of the terrace. Labor cost amounted to 57 per cent of the scraper work expense. The average per acre cost of scraper work was $7.54.

Preliminary compilations of terrace costs using larger machinery indicate that the cost of terrace construction is greatly reduced when using such heavy machinery.

From observation of the operation of low-powered tractors, it would appear that a disk machine somewhat similar to a one-way plow, except with the disk shaft supported and made reversible, would be more suitable than a blade machine. With greater power, the blade scraper is much more satisfactory than with low power.

OPERATION OF FARM MACHINERY. The subject of the operation and design of farm *(Continued on page 312)*

Selection of Channel Grade for Terraces[1]

By H. S. Riesbol[2]

THE PROPER CHANNEL grade for terraces in the Red Plains Region of Oklahoma, Kansas, and Texas has been studied at the Guthrie (Okla.) federal soil erosion experiment station during the period 1930 to 1934 in connection with engineering investigations to determine the most efficient and satisfactory design for terrace systems. These investigations are divided into several experiments, each of which aims at the solution of some particular problem of terrace design.

One experiment affords information concerning the proper vertical spacing for terraces located on the particular soil and slope of the experiment. Terrace 1-A to 6-A (see farm map, Fig. 1) are included. Each terrace is 700 feet long with a uniform grade of four inches per 100 feet. There are two terraces for each of the following vertical spacings: 2, 3½, and 5 feet.

The fact that the different intervals are repeated in reverse order makes possible the elimination of variations due to differences in soil and slope by averaging the results obtained from each pair of identical spacing. The land is virgin with an average slope of 5.5 per cent and served as a wooded pasture prior to experimental use.

Another experiment determines the effect of terrace channel gradient on the conservation of soil and moisture. Measurements are also made to determine the effect of terrace grade on the hydraulic characteristic of the terrace channel, on tillage operations, and on the production of crops. Terraces 3-C to 6-C, located in Field C on the northwestern slope of the farm, are studied in connection with this experiment. These terraces are each 1500 feet in length with respective grades as follows: 6 inches, 4 inches, and 2 inches per 100 feet, and level. As may be seen from the map, the vertical spacing for terraces 4-C, 5-C, and 6-C decreases from about 4½ feet at the upper end to 2 feet at the lower end, and the vertical spacing of 3-C is constant at about 3½ feet. The average vertical spacing of all four terraces is about the same. The land traversed by the lower 500 or 600 feet of these terraces has been in cultivation for several years with some erosion as a result. The remaining portion of the terraces lies on virgin land that was used for pasture prior to experimental use.

It is the purpose of this paper to present an analysis of the theoretical considerations, experimental results, and conclusions from these experiments in order that the agricultural engineer working on terrace design in this or similar regions may have a working basis for selection of terrace channel gradient. In such an analysis it is necessary to consider all factors which have a definite relationship to the terrace design. Some of these factors are referred to and set aside in the following paragraphs on constant factors. Other factors, which are termed as variable, are of particular importance in their effect upon the selection of channel gradient. Each of these variable factors will be attacked both from a theoretical point of view and in consideration of actual experimental results, offering such conclusions as may be justified.

CONSTANT FACTORS. The following factors, referred to as constant, have a definite effect upon the design of terraces but are not intimately tied up with the selection of terrace gradient.

The length of terrace adds drainage area and consequently increases the maximum flow in the terrace channel. Most terrace design specifications call for a variable grade which increases with length of terrace, thus increasing channel capacity by increase in velocity of flow.

As brought out by Duley and Hays at the Kansas Agricultural Experiment Station, by Nichols and Sexton at the Alabama station, and by others, a change in the degree of land slope may entirely change the runoff and soil erosion characteristics of any field. Accordingly all terraces included in either of the above experiments are located on fields of uniform slope in so far as possible to do so.

Change in shape of the terrace channel tends to change the hydraulic characteristics, such as hydraulic radius, coefficient of resistance, and width to depth ratio. For terraces constructed and tilled in a similar manner on land which does not change in degree of slope, there is no appreciable change in the shape of terrace channel.

Terraces 1-A to 6-A and 3-C to 6-C at the Guthrie station are all located on Vernon fine sandy loam soil which has not suffered serious erosion. The effect of soil conditions upon runoff and soil loss from the different terraces is thus comparable from one terrace to another. All terraces are also tilled at the same time and in identical manner, and planted to the same crop.

VERTICAL SPACING. Before beginning an analysis of the variable factors affecting terrace channel gradient, it is essential that a clear understanding be had of the effects of vertical spacing upon the design of a terrace system.

Study of major storms at the Guthrie station indicates that the intensity or rate of runoff is not primarily controlled by the vertical spacing of terraces. This result is in accord with hydraulic theory, namely, for a given amount of surface runoff the maximum rate will be a function of velocity of flow which is in turn controlled by the average slope of land or grade of channel, and by the surface cover. Taking as an example a major storm which occurred on September 9 and 10, 1934, the maximum rates of runoff in inches per hour from the terraces in the experiment on vertical spacing were 3.34 and 3.02 for the 2-foot vertical interval, 3.54 and 3.66 for the 3½-foot vertical interval, and 3.71 and 3.42 for the 5-foot vertical interval. This storm is typical of other important storms.

Study of runoff in per cent of total rainfall for each storm shows definitely that this factor decreases as the vertical spacing of terraces is increased. This relation appears to be more pronounced as the intensity of rainfall is increased, and as the degree of saturation of the soil prior to the storm is increased. The variation does not appear to be materially affected by the type of cover. The six terraces in the experiment on vertical spacing supported a row crop of corn during the years 1931 and 1933, and results have been averaged for these two years. The average runoff in per cent of total rainfall from each pair of terraces with spacings of 2, 3½, and 5 feet was, respectively, 21.80, 22.10, and 18.60. During the years 1932 and 1934 these terraces supported a crop of oats during the spring season and results have been averaged for these two years. The average runoff in per cent of total rainfall from each pair of terraces with spacings

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of 2, 3½, and 5 feet was, respectively, 25.80, 23.80, and 19.30. This decrease of total runoff with increase in vertical spacing is probably due to the increased flow distance between terraces of wider spacing with consequent greater opportunity for percolation into the soil. The terrace channel becomes puddled and quite impervious during a period of runoff, and, therefore, as the proportion of total terrace drainage area represented by the channel is increased, the percentage of rainfall appearing as runoff is increased.

Inspection of soil loss records from individual terraces proves that soil loss increases directly with the vertical spacing of terraces when the field is bare or in a clean cultivated crop. On September 9 and 10, 1934, the field was fallow and soil loss in tons of dry soil per acre was 1.15, 1.40, and 2.01 for the 2, 3½, and 5-foot vertical intervals, respectively. For the years 1931 and 1933 the field was planted to corn in clean cultivated and contoured rows. The annual soil loss in tons of dry soil per acre as averaged for each pair of terraces with identical vertical spacings for these two years was 2.65, 4.15, and 4.97 for the 2, 3½, and 5-foot vertical intervals, respectively. The above data indicate that clean cultivated row crops or fallow condition permit the run-off water which flows down the slope between terraces to gain volume and velocity as the slope distance increases, thus forming small gullies which increase in size and number as the slope distance is increased. The load of soil removed from the interterrace area by this network of changing rills is deposited in the terrace channel where channel flow carries part of it to the outlet of the terrace.

When the terrace drainage area is supporting a close-growing, drilled crop such as oats the soil loss in tons of dry soil per acre is not materially affected by change in the vertical interval. With a three-year rotation of corn, cotton, oats, this ideal state of protection exists only three months out of the year. The annual soil loss in tons of dry soil per acre as averaged for each pair of terraces with identical vertical spacing for the two years 1932 and 1934 was 3.38, 3.47, and 3.97 for terraces with vertical intervals of 2, 3½, and 5 feet, respectively. During both these years the principal crop was oats, but in 1934 the most erosive rains occurred in the fall when the ground was bare, and consequently the average soil loss increased somewhat with vertical spacing.

In summation of the above data the following conclusions are apparent:

1 The maximum rates of runoff per unit of area are not vitally affected by change in vertical spacing.

2 The per cent of the rainfall which appears as runoff decreases as the vertical interval between terraces is increased. In an analysis of various terraces from the standpoint of grade of channel and in relation to moisture conservation, it will be necessary that only terraces of like vertical spacing located on land of similar slope be compared.

3 Soil loss per acre increases directly as the vertical spacing is increased when the ground is in fallow, or cropped to clean cultivated row crop. This conclusion is of extreme importance in a study of terrace gradient, since it indicates that vertical spacing is the criterion of soil loss from the interterrace area, or, in other words, determines the soil content of the water which reaches the terrace channel.

EFFECT OF CHANNEL GRADE ON RUNOFF CHARACTERISTICS. Data collected from terraces 3-C to 6-C, which constitute the experiment on grade of terrace channel, indicate that the runoff characteristics of a terrace are dependent almost entirely on the gradient of the terrace channel.

The so-called rational runoff formula is written $Q = CIA$, in which Q is the rate of runoff in cubic feet per second, C is the runoff coefficient representing the ratio of the rate of runoff to the rate of rainfall, I is the rainfall intensity during the "time of concentration," in inches per hour, and A is the watershed area in acres.

The time of concentration of runoff from any area is defined by Mr. C. E. Ramser in his statement of the rational method of computing runoff as follows: "The maximum rate of runoff from any watershed area for a given intensity of rainfall occurs when all parts of the area are contributing to the flow. That part of the watershed nearest the outlet must still be contributing to the flow when the water from the most remote point on the watershed reaches the outlet. To fulfill this condition the rain must continue as long as is required for the water to travel from the most remote part of the watershed to the outlet or gauging station. This interval is called the time of concentration for the watershed."

From a study of the formula, $Q = CIA$, it will be apparent that Q increases directly with increase in I, and since it is a well-established fact that rainfall intensity increases as the time interval decreases, it follows that the maximum rate of runoff from equal areas will occur for the one having the shortest time of concentration.

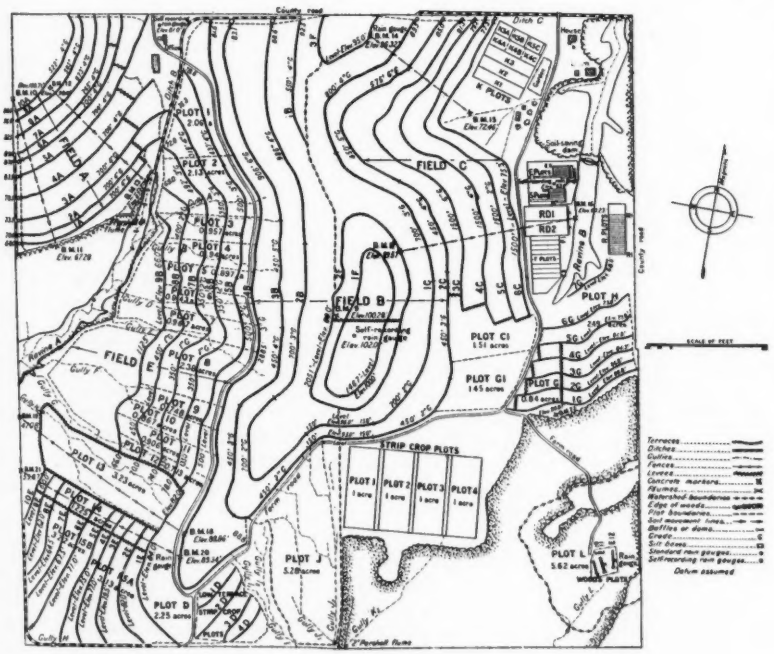


Fig. 1 Farm map (1934) of the Red Plains soil erosion experiment station of the U. S. Soil Conservation Service near Guthrie, Oklahoma

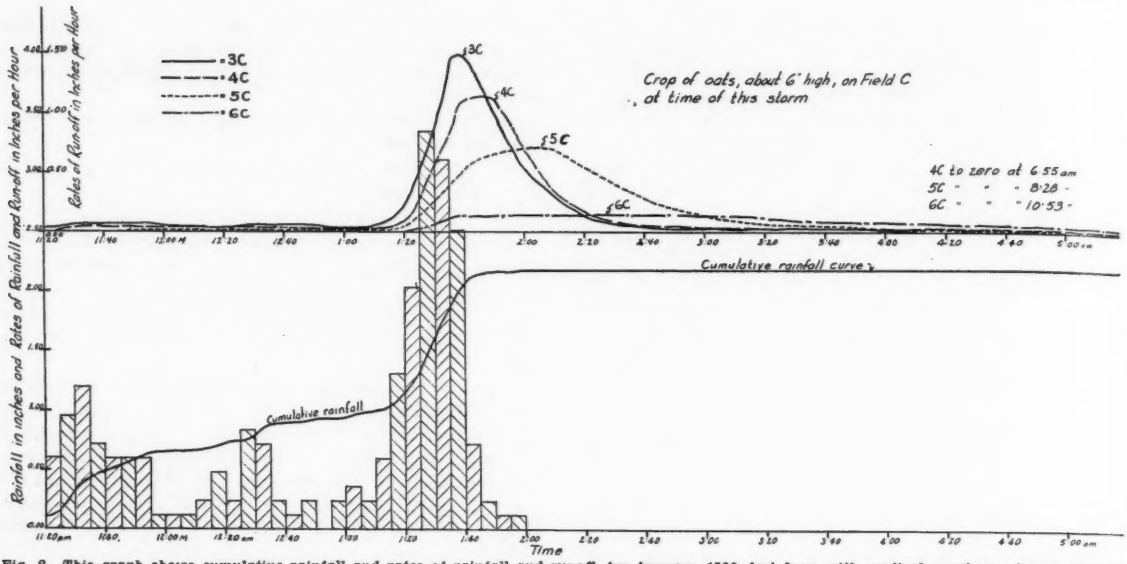

3C
4C
5C
6C
Crop of oats, about 6' high, on Field C at time of this storm
4C to zero at 6.55 am
5C " " " 8.28 "
6C " " " 10.53 "
Cumulative rainfall curve
Cumulative rainfall
Rainfall in inches and Rates of Rainfall and Runoff in inches per Hour
Time

Fig. 2 This graph shows cumulative rainfall and rates of rainfall and runoff for terraces 1500 feet long with vertical spacings of approximately 3½ feet and grades as follows: 3C = 6 in per 100 ft; 4C = 4 in per 100 ft; 5C = 2 in per 100 ft; 6C = level—for rain of May 3, 1934, at the Red Plains soil erosion experiment station near Guthrie, Oklahoma

A study of terraces with different grades at the Guthrie station indicates that time of concentration decreases decidedly as the grade of terrace channel is increased. Fig. 2 shows graphically the cumulative rainfall and the rates of rainfall and runoff from the terraces in this experiment for the storm of May 3, 1934. In this graph the time interval between the peak of rainfall and the peak of runoff is 8 minutes for terrace 3-C with grade of 6 in per 100 ft, 16 minutes for terrace 4-C with grade of 4 in per 100 ft, 32 minutes for terrace 5-C with grade of 2 in per 100 ft. For the level terrace 6-C, the flow did not reach a distinct peak but maintained a uniform discharge for a period of over one hour. The maximum discharge from each of the terraces in inches per hour, or approximately in cubic feet per second per acre, was 1.46, 1.13, 0.71, and 0.14 for the 6 in per 100 ft, 4 in per 100 ft, 2 in per 100 ft, and level grades, respectively. The results from this storm are typical of those from other major storms and prove that as the channel grade of a terrace is increased the time of concentration of flow will decrease and the maximum runoff per acre will increase, in accordance with the theory outlined in the preceding paragraph.

The duration of runoff, or time interval from start to cessation of flow, is also of interest. Returning to the typical storm of May 3, 1934, the duration periods were 5 hours 10 minutes, 7 hours 31 minutes, 8 hours 40 minutes, and 9 hours 33 minutes for the terraces with 6 in per 100 ft, 4 in per 100 ft, 2 in per 100 ft, and level grades, respectively.

Analysis of these runoff characteristics leads to the following conclusions:

1 Time of concentration of runoff decreases as the grade of the terrace is increased. Since all the terraces are of the same length, it is evident that this time difference is a result of increased velocity of flow in the terrace channels of steeper grade.

2 The maximum rate of runoff per acre increases directly with increase in grade of terrace, and for this reason the terraces of steeper grade must have greater channel capacity at their lower ends, and the capacity of terrace outlet structures must be increased. The net result is that the cost of building and maintaining terraces and outlet structures is larger for the terraces of steeper grade.

EFFECT OF CHANNEL GRADE ON MOISTURE CONSERVATION. The comparative ability of level terraces and of terraces with various grades to conserve moisture for the growth of crops has been carefully observed at the Guthrie station. It should be clearly understood that results from terraces located on the shallow sandy loam topsoil and impervious clay subsoil of this station are not applicable to more permeable soils.

For the four-year period 1931 to 1934 inclusive, the total runoff in per cent of the total rainfall from the three graded terraces has been 21.7, 21.8, and 22.1 for the 6 in per 100 ft, 4 in per 100 ft, and 2 in per 100 ft grades, respectively. It is apparent that variation of the grade of the terrace channel has little, if any, effect upon the total amount of runoff. During this same period the total runoff in per cent of the total rainfall from the level terrace 6-C was only 16.9, or 77 per cent of the average total runoff from the graded terraces. This difference in total runoff between the level and graded terraces is most pronounced for rains of low or moderate intensity which fall on dry soil. For example, take the storm of May 13, 1933, during which 1.75 inches of rain fell on fairly dry soil with a peak intensity of 3.48 inches per hour for a ten-minute period. The resultant runoff in per cent of total rainfall was only 14.7 on the level terrace as compared with a minimum of 37.5 on the three graded terraces. For storms of high intensity which occur on saturated soil, this difference in total runoff between the level and graded terraces is hardly discernible. The rain of September 9 and 10, 1934, in the amount of 3.98 inches, with a maximum intensity of 4.56 inches per hour for a ten-minute period, fell on saturated soil. The runoff in per cent of the total rainfall was 58.5 for level terrace 6-C as compared with a maximum of 66.8 for the three graded terraces.

Soil moisture determinations made in the channels of the four terraces in this experiment by H. G. Lewis, superintendent of the station, in the growing season of the year 1934 show soil moisture percentage of 12.52 for the level terrace 6-C as compared to 12.83, 12.93, and 13.75 for

terraces with grades of 2 in per 100 ft, 4 in per 100 ft, and 6 in per 100 ft, respectively. This apparent lack of moisture conservation by the level terrace is further demonstrated by comparison of crop yields from the four terraces. During the four years of record the level terrace has consistently produced less crop per acre than terraces 4-C and 5-C with grades of 4 and 2 inches per 100 feet, respectively. This evidence, while not entirely conclusive, suggests that in the Red Plains region the difference in runoff between the level and graded terraces does not percolate into the soil and become available for crop growth, but is dissipated in some other manner. Observation of the field after numerous storms leads to the conclusion that much of this difference in total runoff is held in the level terrace channel as long, shallow ponds which are lost by evaporation into the air rather than by percolation into a saturated and nonpermeable soil. This pondage results from deposits of silt in the channel of the level terrace. These deposits are caused at sharp bends and at the ends of the terrace by tillage operations and also originate from interterrace erosion as discussed in the following paragraph.

EFFECT OF CHANNEL GRADE ON SOIL LOSS. The erosion which occurs on the drainage area of a terrace may be properly classified into two divisions, namely, interterrace erosion which takes place on the area above the terrace channel, and channel erosion which is limited to the actual water channel of the terrace. Interterrace erosion is not affected by the grade of the terrace channel but is controlled by the crop and tillage scheme and by the vertical spacing of the terraces as previously discussed in this paper. The effectiveness of the methods used to control interterrace erosion determines the amount of soil which will reach the terrace channel.

Erosion or scour in the terrace channel is dependent upon the velocity and volume of flow. For terraces alike in drainage area and other characteristics the velocity and maximum discharge are dependent upon the grade of the terrace channel. A study of total soil lost from these terraces for the four-year period 1931 to 1934, inclusive, shows that the ratio of soil loss per acre from each of the graded terraces to the level terrace is 4.41, 2.63, 2.10, and 1.00 for the 6, 4, and 2-inch per 100 feet, and level grades, respectively. By averaging the annual ratios, that is, giving each year equal weight, the ratios are 4.73, 2.98, 1.96, and 1.00. It is therefore apparent that the rate of removal from the terrace channel of soil deposited there by runoff from the interterrace area is dependent almost entirely upon the grade of the terrace channel.

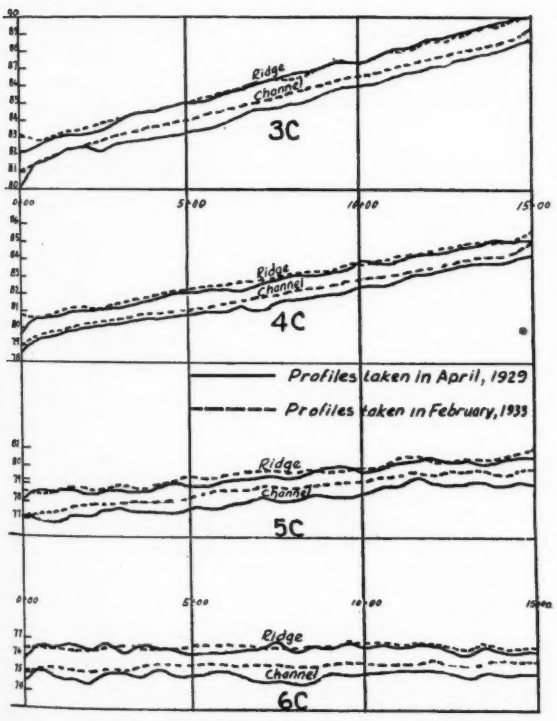


Fig. 3 Terrace profiles for Field C at the Red Plains soil erosion experiment station

Observation of the drainage area and channels of the terraces following all important storms has indicated that greatest concentration of flow and consequent erosion in the interterrace area has occurred at depressions. These concentrations of flow drop their load of silt immediately upon entering the quietly flowing water in the terrace channel. The result is that a delta or mound of silt is formed in the terrace channel below each depression in the drainage area. Profile levels of the channels of these terraces (see Fig. 3) indicate that velocity of flow in the channel of the terrace has not been sufficient to uniformly distribute these deltas along the channel of the terrace. This has left a series of high points in the channel of the level terrace which are responsible for the pondage previously discussed under the heading of moisture conservation. In the terrace having a grade of 2 inches per 100 feet there is also some slight indication of this delta-forming action, but on the terraces having grades of 4 and 6 inches per 100 feet, there is no indication of such action. It appears that on the terraces of steeper grade the velocity of flow is sufficient to pick up the deltas and distribute them uniformly along the channel, or perhaps to remove them from the field entirely. Observation has also shown that on the channel of 6-inch grade the velocity of flow causes scouring in the channel with a resultant loss of many plants, if the crop happens to be small at the time of the storm. It is a matter of conjecture as to whether the scouring in the channel of 6 inches per 100 feet grade removes more soil than is deposited there from the interterrace area, or if the low velocity of flow in the level channel removes only a small portion of the deposited soil. Such action would no doubt vary greatly with the intensity of the particular storm and the cover and tillage conditions of the soil at the time of the storm.

EFFECT OF CHANNEL GRADE ON CROP YIELDS AND TILLAGE. The lowest yield of crop from the four terraces in the experiment on terrace gradient has occurred each year from the level terrace and the terrace with grade of 6 inches per 100 feet. The best yields have come from the terraces with moderate grades of 2 or 4 inches per 100 feet. Drowning of the crop in the channel of the level terrace due to pondage and scouring of the crop in the terrace of 6 inches per 100 feet, as previously discussed, are believed to be responsible for the lowered yields in each instance. The following tabulation shows the yields from these areas for each year of record:

Terrace	Year	Crop	Yield
3-C	1931	Oats	21.0 bushels per acre
	1932	Cotton	574.7 pounds of seed cotton per acre
	1933	Corn	2.54 bushels per acre (practical failure)
	1934	Oats	11.56 bushels per acre
4-C	1931	Oats	23.00 bushels per acre
	1932	Cotton	597.1 pounds of seed cotton per acre
	1933	Corn	4.53 bushels per acre (practical failure)
	1934	Oats	14.26 bushels per acre

5-C	1931	Oats	25.60 bushels per acre
	1932	Cotton	668.20 pounds of seed cotton per acre
	1933	Corn	4.95 bushels per acre (practical failure)
	1934	Oats	14.61 bushels per acre
6-C	1931	Oats	22.80 bushels per acre
	1932	Cotton	492.3 pounds of seed cotton per acre
	1933	Corn	4.77 bushels per acre (practical failure)
	1934	Oats	9.10 bushels per acre

Pondage in the channel of the level terrace has another bad effect, in that it keeps the channel too wet to till for sometimes as long as a week after all graded terraces are satisfactorily tilled. If such a condition were to occur just prior to the optimum date of planting, it is obvious that the yield of crop from the level terrace might be seriously decreased due to unavoidable delay in the planting operation.

MISCELLANEOUS FACTS ABOUT THE LEVEL TERRACE. There are several facts of considerable importance which concern the level terrace, either pro or con, that do not fit under any heading used elsewhere in this paper.

1 It is considered important by some engineers engaged in the construction of terraces that the direction of flow of a level terrace may be changed at any time. This point would be of particular value should it be necessary to change the location of roads and fences affecting the disposal of water from the terrace system. Careful planning of the original terrace system by a competent engineer should in most cases obviate the necessity of such change.

2 If the channel of a terrace is maintained uniformly level, the water flowing in that channel during periods of runoff will be at a nearly constant depth from one end of the terrace to the other. If the ridge of the terrace were maintained to an absolutely uniform height, it would act as a long spillway and overtopping would cause no serious damage. Unfortunately, however, such maintenance is rare, and the water is more apt to pick a low point in the ridge and flow through there in a concentrated stream. In a graded terrace, on the other hand, the water is conducted quickly to the outlet end, and it is only the lower section of the terrace ridge which has to be so carefully maintained. If the grade is excessive, that is, over 4 inches per 100 feet, the water tends to pile up at the lower end, and the ridge at this point must be maintained at excessive height.

3 It has been suggested that a level terrace may be given a greatly increased emergency discharge capacity by the used of "safety gaps," in which case the terrace would discharge from both ends. This suggestion is theoretically sound, but from a practicable viewpoint it possesses certain disadvantages. The farmer in the use of his tillage tools is apt to forget the necessity of maintaining an opening at more than one end of the terrace, and as a result a levee may develop at the safety gap. Grasses and weeds are apt to grow in or near the safety gap and in course of time may build up a natural dam through the deposition of silt.

CONCLUSIONS

It is not the purpose of this paper to present rigid rules for the selection of terrace grade, but to summarize available theory, research, and practical suggestions on this subject as governed by the soils, agriculture, and climate of the Red Plains Region. These factors, as developed in this study, are briefly summarized in the following conclusions:

1 Under conditions of fallow or clean cultivated row crop, the soil removed from the drainage area above the terrace channel is controlled largely by the vertical spacing of the terraces.

2 The time of concentration of flow from any terrace decreases as the grade of the terrace channel is increased. This results in high velocities of flow in the channels of steeper gradient.

3 Maximum rate of runoff per acre increases directly with increase in the grade of the terrace channel, and it is therefore necessary that the terraces of steeper grade have greater channel capacity at the lower end and that the capacity of terrace outlet structures be increased accordingly.

4 Deltas of silt, which remain in the channel of the level terrace due to low velocity of flow, are responsible for the formation of long and shallow ponds. In the Red Plains region this pondage creates the following conditions, not encountered in the graded terraces:

(a) Total runoff from the level terrace is less than that from the graded terraces; the difference is held in the ponds in the level terrace channel from which it is dissipated by evaporation.

(b) The crop yield from the level terrace is lowered due to drowning of the crop in the channel.

(c) Tillage operations are often delayed in the channel of the level terrace as compared to the graded terraces by wet soil conditions.

5 The rate of removal from the terrace channel of soil deposited there by runoff from the interterrace area increases directly with increase in the grade of the terrace channel.

6 It has been suggested that the direction of flow of a level terrace may be changed at will by changing the location of the outlet.

7 If the channel of a terrace is maintained uniformly level, the water flowing in that channel will be at a nearly constant depth from one end of the terrace to the other. The probability of water overtopping the ridge at a low point is equally great regardless of distance from the outlet. In a graded terrace the water is conducted quickly to the outlet, and it is only the lower section of the terrace ridge which needs careful maintenance. If the grade is excessive, that is, over 4 inches per 100 feet, the water tends to pile up at the lower end, and this section of the ridge must be maintained at excessive height.

Engineering Studies in Soil Erosion

(Continued from page 307)

machinery is one that would warrant a much longer discussion than this paper allows. Only a brief discussion will be given here.

Practically the entire work of the farm has been carried on with tractor-operated machinery. Of these operations, that of row-planting and cultivation have been unsatisfactory. Seeds have often been planted either too deep or too shallow on rough land as well as over the terraces. Plowing with moldboard plows has been unsatisfactory due to the shortness of the period when the soil is not too hard or too wet, and to the breakage caused by roots, stumps, and rock in the ground. Better results were obtained by plowing with a rigid-hitch, two-disk plow. With a wheel-type tractor a swinging-hitch plow is difficult to control on steep and terraced land. Some difficulty was observed in running a binder and mower with 7-foot blade over the steeper fields having narrow, high terraces, although in general this size mower gave satisfactory service. An 8-foot drill needed considerable strengthening to stand the strains caused by operating over such rough ground. Other farm machinery worked better. A crawler-type tractor used for a few months on the farm seemed better adapted to conditions than did wheel-type tractors. It was not used for plowing, however, as no suitable plow was available.

Tallapoosa County's Terracing Program[1]

By F. N. Farrington[2]

"GOOD TERRACES Point the Way to Prosperity" has become a slogan in Tallapoosa County, Alabama. "We Build" is the motto of one of the leading civic clubs of America. This motto with a slight change has been adopted by the citizens of Tallapoosa County—"We Build Terraces."

Saving the soil of Tallapoosa County is the key thought travelling the channels of the minds of every citizen in the county. This has been brought about by very carefully planning a county-wide educational program on soil conservation.

In the spring and summer of 1932, the farmers of Tallapoosa County and farm leaders of the county and state realized that the farm industry of the county had suddenly come to the cross roads with no sign boards pointing out the way that they might travel. The roads that they had journeyed over had washed out. The future looked dark and gloomy, and it seemed that the farmers in the county were at a loss as to what course to pursue.

The county agricultural agent and J. B. Wilson, extension agricultural engineer for the state of Alabama, asked these good farmers and business people to await a time with patience until the various routes could be inspected and a better way determined. "All roads were actually travelled." On travelling these roads, it was found that a great deal of construction work had to be done before anyone would be safe in advising the 3320 farmers in the county to move on. It was realized that until Tallapoosa County could formulate some program whereby her soil could be saved from the great monster, soil erosion, the farmers in the entire county would be doomed.

The greatest depression Tallapoosa County farmers have ever experienced has been caused by eroded soils. From investigation, it was found by the author and Mr. Wilson that there was not a cultivatable terrace to be seen in sight of one of the state highways traversing the county in a distance of approximately 45 miles. Bench terraces covered with briars, bushes, and rocks were the only methods of soil erosion control noted on the many fields along this particular highway. The land had washed away, and at least 25 per cent of the area was out of production due to these bench type terraces. This is only an example of what one would have expected to see at that time by riding over the entire county, with the exception of a small area in the Coastal Plain.

Proof of the depressed condition of the county is clearly revealed by data secured from the statistical report of 1930, showing that a family of five had to cultivate 82.5 acres including 15 acres of improved pastures for a decent living. With a vivid picture of the farm life and the poor soil of the county, not poor because God made it so, but poor because of the lack of a proper farm program, the author with his co-workers set out to formulate a program whereby the county could be saved from destruction and that the farmers and citizens who were the taxpayers might be able to make a decent living, educate their children, and have as near modern home life as possible. Hence the Tallapoosa County plan was inaugurated.

A terracing school was arranged, to begin on September 1, 1932. Young enthusiastic farmers from various communities of the county were selected to attend this school. We tried to get for this school young men graduates of high school who had a good farming background and willing to serve their communities. Out of the thirty attending the school, sixteen were awarded certificates. Each farmer receiving a certificate had to complete a three-day course which consisted of learning the fundamentals of a county terracing program, learning to operate terracing equipment, and getting out in the fields and actually doing the work in laying off and constructing terraces. Before these certificates were awarded, each man had to terrace his own farm. This not only gave the licensed terracer a better knowledge of what proper terraced lands were and how terraces could be constructed and maintained, but served as a demonstration in his community carrying out the county program.

Each licensed terracer had to do the work on his farm with what equipment be had at hand, which usually consisted of a homemade drag made from planks picked up on the farm and two mules weighing about 900 pounds each,

[1]A paper presented at a session of the Soil and Water Conservation Division of the American Society of Agricultural Engineers during the 29th annual meeting of the Society at Athens, Georgia, June 1935.

[2]County agricultural agent, Tallapoosa County, Alabama.

Two views of terrace building with Allis-Chalmers equipment—Model KO tractor and No. 8 terracer

and so old and slow they should have been in a county home especially for the poor dumb brutes.

After a year's experience in trying to help these farmers do the actual work on these farms, it was found that the construction part of the program was very weak. The heavy red land in the Piedmont section of the county could not be handled with the equipment the farmers had, and the lack of horse power was found to be a very weak spot in the program. After this year's experience, we realized it would be impossible to do the work with the equipment we had. Therefore, we began to try to find out how the job could be done. During this time another terracing school was held and approximately thirty men attended. Out of this group, ten men received certificates as licensed terracers.

After a year's experience with the above type of program, we began to analyze just what we had done and to try to find out what other method could be used to improve our program. The work that had been carried on in training men to do the most essential job in the whole program, that is, the proper placing of terraces, the study of the general topography of the land, and to become terracing minded, we realized we had done no little job, but had done the most essential thing in a county's terracing program.

With the past experience and the hope of the future, the county agent and the state extension agricultural engineer during the summer of 1933 met with the county commissioners court of Tallapoosa County and discussed the program of terracing land and the possibility of doing it on a custom basis with power equipment. We were there to ask the court for something that we knew very little about, and we had no statistics or actual figures to base any argument on. Terracing had been done with power equipment on private farms, but so far as we could find out, there had never been a program set up whereby farmers could pay a certain amount to a cooperative organization and secure power equipment on their farms to do terracing or other needed operations. But having a commissioners court very willing to cooperate and a real need for a program, we worked out with the court and other good substantial cooperatives a method whereby we could place one tractor outfit in the county for terracing purposes alone. We decided to try this on a six weeks' trial basis.

After we had the consent of the county officials to try a project of this kind, we carried the program to the farmers to find out how they felt about it. We had forty-nine farmers to sign a prospective terracing list, not a contract by any means, but they pledged themselves to have terracing done if we could work up a program of this kind. Later a small group of farmers and the county officials organized what is now known as the Soil Erosion Club.

The Soil Erosion Club was organized for the purpose of sponsoring the county's program, to sell the idea to the farmers and the business men of the county. Plans were made to take this one tractor outfit and build terraces on demonstration fields scattered throughout the county in very noticeable places where farmers could look at them and in this way sell the program to farmers of the county. Officers were elected to the Soil Erosion Club: Walter Strother, county commissioner, president; Leroy Langley and John Elkins, vice-presidents. A committee of three was elected to look after the business of the Club. This committee consisted of Walter Strother, county commissioner; W. J. Hicks, president, Tallapoosa County Exchange; T. E. Sanders, president, Tallapoosa County Farm Bureau. It was their duty to select a secretary-treasurer to look after the general routine and to offer any suggestions that might improve the functioning of the Club.

We started the first outfit September 7, 1933. Of course the first work was an experimental project. The first outfit consisted of a rebuilt tractor and a terracer borrowed from the J. D. Pittman Tractor Company at Birmingham, Alabama, with an option to buy any time during the first six weeks. Everything we tried was a new adventure. We had no experience to base our operations on, nothing to determine a fair price to the farmer, and we had no idea of how much per hour should be set aside for the liquidation and machinery depreciation. But we were doing something that looked good and something that appealed to the farmers.

Soon after starting, we found demands for terracing growing so fast that it was impossible to move the first outfit out of the community where it first started. When the outfit started on a farm, every farmer in the community would come around and watch the work going on. We had a method demonstration every hour we ran, and farmers who lived on adjoining land invited us to move over to their side before we got out of the community.

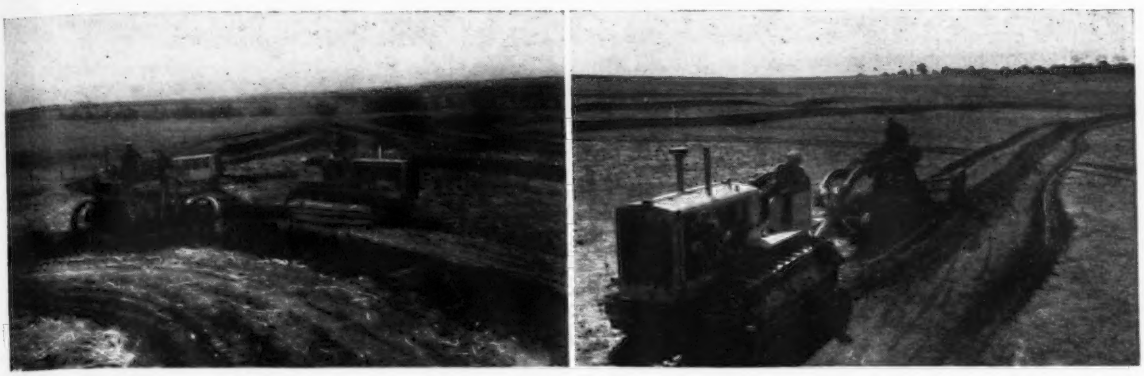
Immediately after starting the first outfit, we saw the need of a business organization. The county officials decided to purchase the outfit we were using for demonstration work, and a special meeting was called by Judge J. Percy Oliver, and a county agricultural department was set up as a business organization for the program. One of the clerks in the county agent's office was appointed by the court as secretary-treasurer of the agricultural department. It was her job to make out bills and receive money for jobs and disburse money for labor, fuel, repairs, and depreciation. About the time this business organization was set up, farmers throughout the county began to find out what this outfit was doing in the community where it started, and they became very anxious for an outfit to start in their own community. They made pleas to their county commissioner, and from that time on the county agent has not had to ask the commissioners court to purchase equipment for their various communities, as the farmers have done the asking.

The commissioners in their respective districts made arrangements with the court for an outfit to start in their community until there was finally one tractor bought for each commissioner's district. This made a total of five for the county bought during the season of 1934. At one time during the season, six outfits were running for the county, including one borrowed from J. D. Pittman Tractor Company.

It seems there are more people concerned about how the terracing equipment was bought than any other function of the program. The county at the time it organized the county agricultural department made arrangements for the purchase of equipment for this organization. The arrangements were that the county purchase all equipment for the department by issuing county warrants, payable in four payments of six, twelve, eighteen, and twenty-four months. These warrants are made payable to the county agent, and he endorses them over to the tractor people. Should the county agricultural department fail to liquidate the warrants, the county either pays them or issues new warrants, payable at a later date.

Since these arrangements were made, it was decided by the county to take up all outstanding warrants; therefore, the county agricultural department makes its payments direct to the county. We purchased during the fall of 1933 approximately $5,000.00 worth of terracing equipment which in the main consisted of second-hand equipment. We paid $2,000.00 on this equipment during the first terracing season. This was paid by checks drawn on the Tallapoosa County agricultural department as money was collected from the farmers and deposited in this fund, a certain amount being included on each bill for tractor depreciation.

We were out a considerable amount of expense during



Caterpillar equipment in terrace building. (Left) Diesel 50 tractor pulling No. 60 elevating grader. (Right) Diesel 35 tractor and No. 33 grader

the first part of the year due to the fact that our equipment was not suited to the type of work we were trying to carry on. The right kind of equipment was not available at that time. In our first operations, we used rebuilt tractors of 25 and 30 hp, which proved to be too small for the job, and the No. 1 terracing machine, which also proved to be too weak for custom work. We were to a great deal of expense in keeping the outfits reinforced and rebuilt in order to carry on our work. At the end of the season, we were in the market for modern terracing equipment for rugged use.

Since the Caterpillar Tractor Company had been cooperating with us from the beginning of the program, they had begun to realize that there would be a future in such a program. They had already shown a great deal of interest in the work, even from the beginning, and in the early spring of 1934 they sent their designing engineer to Tallapoosa County to study the program and its possibilities, and especially for the purpose of designing a terracing machine that would be well suited to the work. After spending two weeks in Tallapoosa County and at the experiment station, this designing engineer returned to the factory. On leaving the county he assured us that within sixty days we would have a new terracing outfit in Tallapoosa County, and he was true to his word. On March 17, 1934, we purchased our first Diesel 35 tractor and the first No. 2 terracer built, and started on a revised program.

As the result of soil erosion control in Tallapoosa County from the first terracing season with our equipment, we terraced 6500 acres of land for 126 farmers at an average cost of $1.69 per acre. The farmers paid the terracing organization more than $10,000.00 for the improvement of their land. It was a very desirable year for terracing, the seasons were just right, and although our equipment was not what we really needed, we considered the first year's program a real success. A great deal of our success during the first season can be attributed to ideal weather conditions.

Tallapoosa County's terracing program during its first season was not only building ridges across fields to slow up fast-running water, but along with this terracing program a very concerted effort was made to get the farmers to plant winter legumes. As a result of these efforts, the planting of legumes has increased from 23,000 lb in the fall of 1932 to 69,000 lb in the fall of 1933, and to 200,000 lb in the fall of 1934.

The successful beginning of the county's terracing program made it possible for the county to secure the Soil Conservation Service project which is now located in the Sandy Creek basin. It has been said by members of their staff that they had planned to locate their project in the Coastal Plain region of the state, but their minds had been changed due to the fact that the farmers and business men of Tallapoosa County had asked for the project and had shown such a cooperative spirit in the work they had been carrying on, they felt it unwise to try to find a better location. This spirit of cooperation did not only exist during the time of securing the project. It has been the main power in the success of both the soil SCS project and the county program. The cooperative spirit between the two organizations has been so unified, so far as I know, that there has never been a word of dissension from either group.

The county has had two of its outfits within the borders of the Sandy Creek basin all along during the past season, not in competition with the Soil Conservation Service but in cooperation. The Soil Conservation Service has had but a very few who failed to sign for the federal work. The county program has terraced for a part of these few. The other group the county has worked for are farmers who were anxious to get every foot of their land terraced during the first season; therefore, they secured all the help they could from the Soil Conservation Service and then paid the county to finish their work.

In the fall of 1934 the commissioners court realizing more and more the need for better equipment in order that the terracing program might be speeded up to its maximum, at a regular session of their court meeting, traded in all the second-hand equipment belonging to the agricultural department. Four other new Diesel tractor and terracing machines were bought, giving a new outfit to each commissioner's district. And later on in the season two more terracing outfits were bought and one more new Diesel tractor, one of the terracers being pulled by the county's own tractor.

A complete record has been kept on this equipment. Some of the machinery was bought too late in the season to include in working up a year's summary for the outfits; therefore, our statements include only three of the outfits which were run during a full terracing season. These three outfits have averaged 657 hours during the past season. It has not been a desirable year for terracing due to the fact that showers fell frequently, keeping the outfits out of the fields. The three outfits have terraced 2910 acres for 125 farmers at an average cost of $1.55 per acre and an average of 11.8 acres per day for each machine.

The farmers have paid the agricultural department a total of $4,450.97 for terracing done with the three outfits. Of this amount $2,463.75 has gone for tractor depreciation. This $2,463.75 was collected by charging $1.25 per hour for machine depreciation for every hour each tractor worked for the farmers.

The total cost of labor, grease, fuel, and gasoline for these three outfits was $1,987.12. The same outfits plowed during the spring, and there was another $285.00 made available for paying on the depreciation from this operation which brought the total amount to $2,748.75. We have actually paid and have receipts on these three outfits $2,650.00, and it looks as if we will have something like $800.00 more to pay on them when our collections are brought up to date and before next year's season starts on September 1.

We have had a little overrun ever since the program started. This is due to the fact of having efficient labor in laying off lines, one line crew being able to stay ahead of as many as three tractors; however, the same amount was charged out to the farmers as if the fellows laying off the lines had spent as much time as the tractor men did. Another great factor in a successful terracing program is efficient labor at a reasonable price. We have not paid over $2.00 per day which we feel is reasonable for farm labor, for all parties concerned.

You will note from the above figures that the cost per acre to the farmer has decreased 14 cents from last year's operation. This is due to better and more economical machines and better trained men. A greater percentage of the total income is being paid for tractor depreciation, and a much better job is being done this year than was done last year with the small equipment. The average cost per acre as given in this outline included work done in the Piedmont section of the county with two tractors and one tractor in the Coastal Plain section. The figures for the other four outfits belonging to the county are available, but they have been run over such a short period of time and so irregular we felt that you would not be interested in those figures.

Appended to this paper are two bills as we sent out to the farmers. One is for the Coastal Plain section and the other for the Piedmont section. These are average bills of all that you will find in our files. We have a terracing foreman who turns in all bills from each crew. These bills are typed by the secretary and are handed back to the terracing foreman who makes collections from the farmers and returns the money to the secretary. Then it is deposited by the secretary-treasurer of the department to this particular fund. All bills such as labor, fuel, oil, grease, gasoline, and tractor depreciation, are paid from this fund. Appended also is sample job report the foreman makes to the secretary when a job is completed.

The success of the program in Tallapoosa County is due to a very cooperating group of farm people, a unified spirit between the farmers and the business men, and a very cooperating county government. It would have been utterly impossible for us to have started had we not had 100 per cent cooperation from our county commissioners court. It has been said by the probate judge and commissioners that, if any program had to be stopped in the county, either the road or terracing, it would be the road program. Our self-liquidating soil erosion program was organized to terrace land in Tallapoosa County. It has done everything we had expected it to do along that line, and, in addition, it has built up an enthusiasm among our entire farming group and business people that cannot be excelled anywhere by any kind of farm program.

An editorial writer from the Middle West, who spent a week in Tallapoosa County studying the program, made this remark on his departure: "I came down to secure cold-blooded facts concerning the terracing of land and the control of soil erosion. I have received this information, but more important than that, I have found a story of romance among the farmers and business people which has been built up as a result of this program."

One of the great features that helped to establish a program of this type in Tallapoosa County was a deposit of a huge bank of soil at the mouth of Sandy Creek where it entered Lake Martin, this soil coming from the watershed of Sandy Creek. The Alabama Power Company pulled this water off for power purposes, leaving the huge bank of soil exposed. It is the author's estimation that at least 1500 farmers and business men observed this real vivid picture of farm loss by soil erosion. It was figured out by one of our commissioners, Walter Strother, that enough soil was deposited in one bank to cover the entire Sandy Creek basin two inches deep. This particular bank averaged 65 yards wide, 465 yards long, and 45 feet deep. This was one of many deposits made around the shore line of the lake. This huge deposit was made in only two years time.

Eleven thousand acres have been terraced by county-owned equipment from the beginning of the program up to date, and the soil conservation group has terraced approximately 10,000 acres. Tallapoosa County and everyone of its citizens are proud of its great farming program. We have gladly welcomed visitors from 44 counties of the state of Alabama, visitors from 38 states in the union, and visitors from 5 foreign countries. A total of approximately 3,000 visiting farmers and business men have observed the Tallapoosa County terracing program. Our business men and farmers gladly welcome all visitors, and we hope to continue our work in such a way that there will be a continued interest among the people of the South and the Nation, and that Tallapoosa County will continue to keep the lead in the control of the great problem the farmers of the nation have, *soil erosion.*

IN ACCOUNT WITH THE TALLAPOOSA COUNTY
AGRICULTURAL DEPARTMENT

Dadeville, Alabama
November 6, 1934

To Ed Reynolds,
Notasulga, Ala.

155 gal fuel at 7c per gal	$ 10.85
10 gal motor oil at 75c per gal	7.50
35 lb grease at 15c per lb	5.25
21 days labor (tractor-machine) at $2.00	42.00
10 days (linemen) at $2.00 per day	20.00
10½ days tractor depreciation at $10.00 per day	105.00
Total	$190.60

146 Acres of Coastal Plain land terraced.

IN ACCOUNT WITH THE TALLAPOOSA COUNTY
AGRICULTURAL DEPARTMENT

Dadeville, Alabama
October 31, 1934

To Raymond Sturdivant,
Dadeville, Ala.

95 gal fuel at 7c per gal	$ 6.65
5 gal motor oil at 75c per gal	3.75
15 lb grease at 15c per lb	3.25
5½ days labor (linemen) at $2.00 per day	11.00
9 days labor (tractor-machine) at $2.00 per day	18.00
4½ days tractor depreciation	45.00
Total	$87.65

40 Acres of Piedmont land terraced.

JOB REPORT

Date—November 9, 1934

Worked for—J. H. Lovelace
Address—Dadeville, Alabama
Work Began—Tuesday morning, November 6
Job Completed—Thursday noon, November 8
Time Worked Tractor—2½ days (8 hr day)
Time Worked Linemen—1½ days
Material used on Job:
40 gallons Diesel fuel
2½ gallons motor oil
12 pounds grease
2 gallons gasoline
Repairs: None
Estimated Acres—30

Signed: L. T. WILSON, Foreman.

Cost of Terracing in Iowa[1]

By Quincy C. Ayres[2]

DURING the three months' period beginning August 1 and ending October 31, 1934, the Iowa Emergency Relief Administration undertook a construction program to aid in combating soil erosion in southern Iowa. The exigencies of the situation were such that the work was limited to the building of terraces and terrace outlets on areas selected by the various county agents, and the construction of checks and soil-saving dams in gullies. All construction work was done under the direction of resident work relief engineers using plans prepared by the author. Approximately 100,000 man-hours of worth-while labor was thus created in rural areas with which farmers could repay the government for feed and seed distributed.

The program was carried out on a total of 145 farms in 18 counties, all located in the southern two tiers. Detailed records of the cost of terracing were kept on 72 of these farms and are now available for study.

Terracing cost is affected by a number of variable factors, chief among which are

1 Texture and condition of soil
2 Prevailing degree and regularity of slopes
3 Extent of erosion at time work is done
4 Availability of erosion-proof natural outlets for terrace channels
5 Kind of implements used
6 Kind of power used to operate implements
7 Dimensions of the terrace channel and embankment
8 Length of terraces, which determines time consumed in turning at ends
9 Experience and skill of operators and technique of building
10 Manner in which work is financed.

Not all of the above factors can accurately be evaluated in a program of the type being studied, but it is believed enough information is available to confine most of them within a probable range of reasonable limits.

A general summation of the data reveals that 500 terraces were built on 72 farms with a total length of 519,484 ft, or 98.4 mi. This makes an average length per terrace of 1039 ft, and an average footage per farm of 7215 or 1.37 miles. The average length of terrace per acre of land protected is 213.3 ft, and per acre of all land in the farm 45.9 ft. The minimum dimensions of grader-built terraces are shown in Fig. 1, and average dimensions of the rotary-plow terraces are as shown in Fig. 2. The cubic yards per lineal foot of embankment ranges from 0.3 to 0.5.

Available implements consisted of steel V-drags and small blade terracers owned by the old four-county erosion associations, plows owned by the farmers, slip scrapers and small road graders loaned by the counties, and the experimental rotary plow which was financed by the Emergency Relief Administration.

Available power consisted of farmer-owned horses and tractors and the Model U, Allis-Chalmers high-speed tractor which was on consignment at Iowa State College and was especially authorized by the manufacturer for use in this program. This tractor, as well as the experimental plow, was equipped with pneumatic tires, and the outfit had an operating speed of 5 to 7 mph and a road speed of 10 to 12 mph.

Work on the 72 farms was divided into the following implement and power combinations:

Equipment	Number of farms
Horses, plow, and scrapers	1
Horses and grader	7
V-drag and 2-plow tractor	8
7-ft blade grader and 2-plow tractor	14
Experimental plow and A-C tractor	42
Total	72

With the exception of the two skilled operators who accompanied the experimental outfit, all labor was performed by farmers and other relief workers who were paid in cash or in goods at an average rate of 30 to 40 cents per hour. Wages of the skilled operators were set at $120 each per month plus traveling expenses, and together they worked from 12 to 14 hr per day, six days per week.

The predominant soil types in the areas worked on were various phases of Shelby, Clinton, Grundy and Marshall silt loams with a sprinkling of Tama, Lindley, and Putnam. One farm in Madison County was reported as black gumbo. The usual soil condition was very dry to dry and hard, although a surprising number of terraces were built in soil described as moist to wet and very wet. The prevailing cover was stubble, but all common types were represented, including plowed, sod, clover, oats, and bare fallow ground.

The effect of soil variables on the cost of terracing is indicated in the following comparisons: On the Scott farm in Taylor County the soil was dry Shelby with sod cover. The prevailing slope was 12 per cent, and a terrace 1000 ft long was built with a steel V-drag and tractor at a rate of 52 machine-hours per mile. On the Kinion farm in Davis County—soil a moist Shelby, sod cover, slope 11 per cent—a terrace 1250 ft long was built with similar equipment at a rate of 29.6 machine-hours per mile. Thus, unfavorable moisture content brought about a 75 per cent increase in the time required for construction.

The influence of texture on costs can be illustrated by comparing the Larson farm in Montgomery County with the Wilson farm in Van Buren County. Terraces on both farms were built by the experimental machine on 10 per cent slopes, and the only essential difference was soil type. Dry Marshall in the first case required 6.8 machine-hours per mile of terrace, and dry Clinton in the second, 11.0 machine-hours.

The effect of variations in topography is three-fold. In

[1]Journal Paper No. J-276 of the Iowa Agricultural Experiment Station (Project No. 424). Released for first publication in AGRICULTURAL ENGINEERING.

[2]Research associate professor of agricultural engineering, Iowa Agricultural Experiment Station. Mem. ASAE.

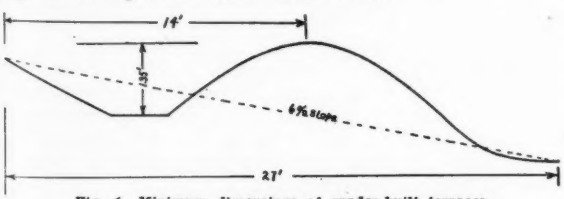


Fig. 1 Minimum dimensions of grader-built terraces

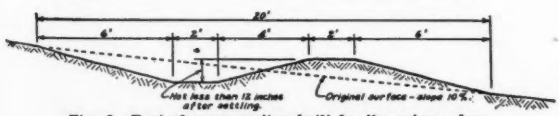


Fig. 2 Typical cross section built by the rotary plow

the first place, terraces on cultivated fields are practical in Iowa only within a range from 3 per cent to 12 per cent, and they are much less costly on flat slopes than on steep slopes, partly because the terrace cross-section is easier to form, but principally because wider spacing permits a given length of terrace to protect a larger acreage. On the third count, non-uniform and irregular slopes require crooked and irregular terraces, which greatly increases the difficulty and cost of construction and necessitates more careful plowing and cultivation and larger expense for maintenance. Blade graders are poorly adapted for crooked terraces on account of the difficulty in negotiating sharp bends.

If the field being terraced is disfigured by small gullies, none of which are too large to cross, the increased cost is reflected in the amount of extra work required to bring the terrace bank up to grade at the points of crossing.

Some idea of the combined influence of irregularity of topography and degree of erosion can be gained by a summation of the extra work required to complete the terraces on the 72 farms for which records were obtained. This is shown in the following tabulation:

	Minimum per farm	Average per farm	Maximum per farm	Average per mile of terrace	Average per acre protected
Man-hours	0	97.8	822	71.6	3.0
Team-hours	0	39.5	369	28.9	1.2

The work required to provide erosion-proof outlets for terraces where none existed naturally was as follows:

	Minimum per farm	Average per farm	Maximum per farm	Average per mile of terrace	Average per-acre protected
Man-hours	0	69.0	651	50.5	2.1
Team-hours	0	6.8	103	5.0	0.2

In interpreting these figures it should be remembered that the chief purpose of the project was to create employment for hand labor.

EFFECT OF VARIATION IN IMPLEMENTS AND POWER. Variation in equipment used in building terraces, as in other forms of construction, usually constitutes the major factor in influencing cost. An analysis of available data from this point of view is summarized as follows:

DAVIS COUNTY—WILLIAM L. CREE FARM
(Exclusive of extra work)

Equipment—Teams, slip scrapers, plow
Soil—Lindley loam, light weight, moist, stubble cover
Number of terraces—7
Total length—3360 ft, or 0.635 mi
Total hours to build—21, or 33.2 per mi
Man-hours labor—161.5, or 254 per mi
Horse-hours power—120, or 189 per mi
Acres protected—15, or 23.6 per mi

Cost of labor per mile, at 30c	$ 76.20
Cost of power per mile, at 14c	26.40
Cost of equipment per mile, at 15c per hr	4.98
Total cost per mile	$107.58
Cost per acre protected	$4.56

DAVIS COUNTY—JOHN McGOWN FARM
(Exclusive of extra work)

Equipment—Teams and V-drag
Soil—Shelby loam, medium weight, moist, sod cover
Number of terraces—4
Total length—3350 ft, or 0.63 mi
Total number hours to build—23, or 36.5 per mi
Man-hours labor—175, or 278 per mi
Horse-hours power—146, or 232 per mi
Acres protected—18, or 28.6 per mi

Cost of labor per mile, at 30c	$ 83.40
Cost of power per mile, at 14c	32.48
Cost of equipment per mile, at 10c per hr	3.65
Total cost per mile	$119.53
Cost per acre protected	$4.18

ADAIR COUNTY—A. S. HAMILTON FARM
(Exclusive of extra work)

Equipment—15-27 tractor and grader
Soil—Tama silt loam, both phases, medium weight, very dry, stubble and sod cover
Number of terraces—6
Total length—8400 ft, or 1.59 mi
Total number hours to build—41.5, or 26.1 per mi
Man-hours labor—72, or 45 per mi
Tractor-hours power—41.5, or 26.1 per mi
Acres protected—30, or 19 per mi

Cost of labor per mile, at 30c	$13.50
Cost of power per mile, at 52c	13.57
Cost of equipment per mile, at 15c	3.90
Total cost per mile	$30.97
Cost per acre protected	$1.63

MADISON COUNTY—J. O. McCLEARY FARM
(Exclusive of extra work)

Equipment—General-purpose tractor and Texas grader
Soil—Sandy loam and clay, light weight, moist, bare and stubble cover
Number of terraces—11
Total length—9300 ft, or 1.76 mi
Total hours to build—32, or 18.2 per mi
Man-hours labor—120, or 68.2 per mi
Tractor-hours power—32, or 18.2 per mi
Acres protected—31.5, or 18.0 per mi

Cost of labor per mile, at 30c	$20.46
Cost of power per mile, at 52c	9.46
Cost of equipment per mile, at 15c	2.73
Total cost per mile	$32.65
Cost per acre protected	$1.79

18 SOUTHERN IOWA COUNTIES—54 FARMS
(Including data kept by operators, and exclusive of extra work)

Equipment—Experimental rotary plow and Model U Allis-Chalmers tractor
Total length of terraces—337,791 ft, or 64 mi
Total hours to build—482.2, or 7.53 per mi
Man-hours labor—482.2, or 7.53 per mi
Tractor-hours power—482.2, or 7.53 per mi
Average horsepower—18.28
Acres protected—1216, or 19 per mi

Cost of labor per mile (skilled) at $1.50	$11.25
Cost of power per mile, at 52c	3.91
Cost of implement per mile, at 20c	1.50
Total cost per mile	$16.66
Cost per acre protected	$0.88

For comparison with these records the author was supplied with confidential data on the performance of three makes of tractors and graders especially designed for terracing. The best record was made by a 40-hp Diesel, track-type tractor, pulling a 1400-lb, 10-ft blade grader. The cost per mile in exceptionally favorable soil on a moderate slope was $16.44. The average cost per mile of terraces built with similar equipment was more than twice this figure. The amount of earth moved, however, ranged between 0.5 and 0.6 cu yd per lineal foot.

On some of the terracing work in Nebraska, where a combination of 5 rounds with a 60-hp tractor pulling an elevating grader and 6 rounds with a 35-hp tractor and blade grader was used, the cost is reported as approximately $28.00 per mile. It would seem that such large and heavy equipment would be hard to manipulate on country roads and bridges and in general would be awkward to handle under most farm conditions.

Some of the advantages of the rotary outfit, aside from low cost, are extreme mobility, utility with ordinary farm power, better workmanship possible at bends in terrace and at ends, small shrinkage in terrace bank, good seedbed due to pulverization of soil, adaptability to a wide variety of soil conditions, and light weight and ease of operation.

The Design of Stilling Basins for Small Dams and Weirs

By Garrett B. Drummond[1]

NUMEROUS observations indicate that flow at the toe of a dam may be classified in five general types as follows:

Roller Action, in which the stream coming over the dam strikes the pool at the foot of the dam and is deflected in a horizontal direction. Friction with the floor and the surface of the pool decreases the velocity of the oncoming stream, and sets up an eddy about a horizontal axis which slopes backward on top toward the incoming sheet of water. This absorbs and dissipates the energy of the falling sheet, and the turbulence is taken out of the water before it causes any damage to the area around the toe of the dam.

Jump Action, which is similar to the type of action above, except that the amount of water handled is not so great. Laboratory observations have shown that this type of action definitely is that of the hydraulic jump.

Incomplete Jump Action, which occurs when the length of the stilling basin is too short to accommodate the hydraulic jump. All of the energy is not absorbed as in complete jump action, and there remains sufficient velocity energy to cause erosion at the toe of the dam.

Pool Action, in which the basin is comparatively short. The water shoots in and out of the basin, being thrown into the air. Less energy is absorbed, and there is formed a roller whose energy is sufficient to cause erosion as in the incomplete jump action.

Spray Action, in which the basin is comparatively shallow. The water shoots across the floor of the basin and is sprayed into the air, with an appreciable amount of energy remaining capable of causing erosion.

PREVENTION OF EROSION AT TOE OF DAM. In this connection it is evident that the solution of the problem of preventing erosion at the toe of a dam consists of the proportioning of design in such a manner that roller action or jump action will be produced at the tail-water area of the dam.

This phenomena was recognized many years ago by the French hydraulist, Bazin, who distinguished between what he designated as "nappes covered by tail water" and "free nappes with a repelled jump." Referring to Fig. 1, line A represents a covered nappe and line B represents a free nappe. Bazin suggested that the presence of one or the other of these types of flow is dependent upon the value of Z/P, which is the ratio of the vertical difference of the levels of the water above and below the dam to the height of the structure.

This problem admits of algebraic solution.

Referring to Fig. 1, for section 1-1, there may be written

$v_1 = \phi\sqrt{2g(P+H-d_1)}$ where ϕ is a velocity coefficient.

Also $q = \phi\, d_1\sqrt{2g(P+H-d_1)}$ ..... [1]

But the discharge over a weir, with a discharge coefficient m, is

$q = m\sqrt{2g}\, H^{3/2}$ ..... [2]

Eliminating q from equations 1 and 2, there is written

$m^2H^3 = \phi^2\, d_1^2(P+H-d_1)$

Dividing both sides of this equation by P^3 and letting $x=H/P$ and $y=d_1/P$, the above equation becomes

$m^2x^3 = \phi^2y^2(x-y+1)$ ..... [3]

It is evident that the condition which will produce a covered nappe or a free nappe is that there shall be produced a depth, t, which shall be greater than or less than the depth, d_2, conjugated through the hydraulic jump to the depth d_1. As the depth t increases, the jump will be moved toward the dam until there will be such a value $t_o = d_2$, which will be the demarcating depth between these two forms of flow.

Expressed by the familiar equation for the hydraulic jump, the above statement becomes

$t_o = d_2 = -(d_1/2) + \sqrt{(2v_1^2\, d_1)/g + d_1^2/4}$

By the substitution of the value for v_1 above, this expression may then be written as

$t_o = d_2 = d_1/2$

$[-1 + \sqrt{1+(16\phi^2/y)(x-y+1)}]$ .....[4]

The geometrical relations of Fig. 1 gives this expression

$Z_o = H + P - t_o$, or $(Z/P)_o = H/P + 1 - t_o/P$

which upon the substitution of the value for t_o above and $x = H/P$ becomes

$(Z/P)_o = x + 1 - y/2$

$[-1 + \sqrt{1 + 16\,\phi^2\,\frac{(x-y+1)}{y}}]$ ..... [5]

Equation 3 and equation 5 above are the solutions to the problem. By equation 3 values of d_1, or y, are determined, and with these values the corresponding values of $(Z/P)_o$ are determined from equation 5.

Solutions of these equations for varying values of H/P and Z/P are given in Table 1. These equations have been solved for the conditions of flow encountered in soil-saving dams and small check dams, and the values given in Table 1 may be used directly.

FLOW OVER SMALL CHECK DAMS. The solution of the problem for flow over a small check dam presents conditions slightly different from that over large dams. The small check dam is essentially a broad-crested weir, and the slope of the approaching channel is so small that the depth of flow over the dam passes through the critical

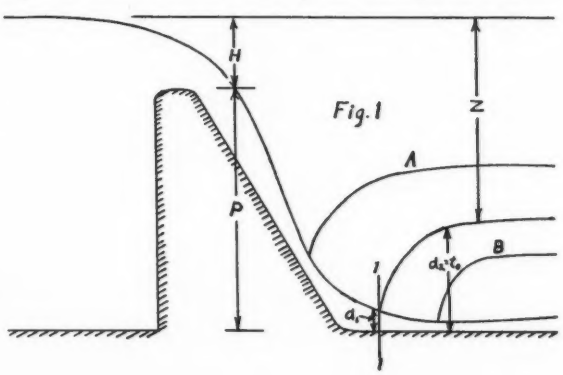


Fig. 1

[1]Assistant professor of mathematics, Oklahoma A. & M. College.

TABLE I. VALUES OF H/P AND Z/P FOR SOIL-SAVING DAMS AND CHECK DAMS

Values of H/P	Corresponding values of Z/P	
	Soil-Saving Dams	Check Dams
0.0	1.00	1.00
0.1	0.87	0.88
0.2	0.83	0.83
0.3	0.80	0.80
0.4	0.77	0.78
0.5	0.76	0.76
0.6	0.75	0.75
0.7	0.74	0.74
0.8	0.73	0.73
0.9	0.72	0.73
1.0	0.72	0.73
1.1	0.72	0.74
1.2	0.72	0.74
1.3	0.72	0.75
1.4	0.73	0.75
1.5	0.74	0.76
1.6	0.74	0.77
1.7	0.75	0.78
1.8	0.75	0.80
1.9	0.76	0.81
2.0	0.77	0.82
2.1	0.77	0.84
2.2	0.79	0.85
2.3	0.80	0.87
2.4	0.81	0.88
2.5	0.82	0.90
2.6	0.83	0.92
2.7	0.85	0.95
2.8	0.86	0.97
2.9	0.87	0.98
3.0	0.89	1.00
3.1	0.90	1.03
3.2	0.91	1.05
3.3	0.93	1.07
3.4	0.95	1.10
3.5	0.96	1.12
3.6	0.97	1.15
3.7	0.98	1.17
3.8	1.00	1.20
3.9	1.02	1.24
4.0	1.03	1.26

depth near the edge. In the case of rectangular sections, as in check dams, the critical depth is $\sqrt[3]{q^2/g}$, and the corresponding energy head is 1.5 times the critical depth, or $1.5\sqrt[3]{q^2/g}$. In this case q is the flow per unit length, or Q/b. The value of H to be considered in this problem is the energy head derived above.

LENGTH OF THE BASIN. It is to be noted that the above solution treats only of the vertical elements of the problem. The length of the basin is a quantity concerning which there remains much experimental work to be accomplished. As the result of various experiments culminating in a thesis at the University of Iowa in 1931, C. M. Stanley observed that the necessary length was between four and five times the depth of the tail water. Observations upon larger dams upon the property of the Aluminum Company of America in Tennessee and North Carolina were recorded in the March 1931 issue of *Civil Engineering*, by R. F. Ewald, who states that the length should be at least five times the conjugated height of the jump. It appears that values of L greater than $4t_o$ and less than $5t_o$ will be sufficient for purposes of design.

The value of t_o may be determined from the relation $P+H-Z=t_o$.

EXAMPLES

SOIL-SAVING DAM, OR LARGE MASONRY DAM. A soil-saving (or large masonry) dam 12 feet high will discharge with a maximum head on its spillway of 4 feet. The depth of the tail water is 6 feet.

Assume H/P equals 4/12, or 0.33; and Z/P equals 10/12, or 0.83.

From Table 1 it is determined that the demarcating value of Z/P for the above value of H/P is 0.78. This means that since the above value of Z/P is greater than 0.78, there will be a free nappe with a repelled jump. The value of Z/P must be reduced by increasing P, or by decreasing Z.

Increasing P by constructing a basin of a depth of one foot, the new value of P will be 13 feet. H/P now becomes 0.31, and the corresponding value of Z/P is 0.79. The new value of Z/P is 10/13, or 0.77. For practical purposes of design, it is probably better in this case to make the basin two feet deep, thus still lowering Z/P.

Instead of constructing a basin, a barrier might have been inserted thus decreasing Z. Utilizing the demarcating value above of 0.78, we have $Z/12$ equals 0.78, or 9.36. By inserting a barrier 1.5 to 2 feet high in the tail water, the stream will be caused to rise over it thus reducing Z to values between 8.5 and 9 feet.

From the above design of the basin, t will be equal to $H+P-Z$, or 7 feet. The length of the basin should then be between $4t$ and $5t$, or from 28 to 35 feet long, depending upon convenience of construction.

A SMALL CHECK DAM. A small check dam 7 feet high has a notch 5 feet wide and 3.5 feet deep. The depth of the tail water is 3 feet.

From Table 3, page 28, "Brief Instructions on Methods of Gully Control," by Ramser, it is determined that Q equals 111.0 cubic feet per second. Then q equals 111.0/5, or 22.2.

The critical depth is $\sqrt[3]{(22.2)^2/g}$, or 2.48.

Then H equals (1.5) (2.48), or 3.72.

And Z equals $H+P-t$, or $3.72+7-3$, or 7.72.

H/P is 3.72/7, or 0.53, and Z/P is 7.72/7, or 1.10.

From Table 1 the demarcating value of Z/P is 0.755.

Since 1.10 is greater than 0.755, the flow will be free with a repelled jump.

A basin 4 feet deep will make P equal to 11 feet.

Now H/P becomes 3.72/11, or 0.33, and Z/P becomes 7.72/11, or 0.70.

For H/P equal to 0.33, the demarcating value of Z/P is 0.79.

Since the new value of Z/P is less than the demarcating value for the new dimension, there will be a covered nappe.

The length of the basin should be between 12 and 15 feet.

* * * *

This method of analysis, which is based upon the writings of Bakhmeteff, has received a novel application on Project No. 9, of the U. S. Soil Conservation Service, near Stillwater, Oklahoma. In connection with the installation of small dams for gully control, J. H. Wheatley, engineer, has utilized the ratios given in this paper for the proper spacing of these small dams. Basing his design upon the theory, that nature will provide its own stilling basins, if the flow of water is properly controlled, Mr. Wheatley has spaced his dams at such intervals that the crest over any particular dam will be at such a distance below the crest of the preceding dam, that the proper value of Z/P will be reached, wherein the resulting flow will be such that a cover nappe will result.

More than five hundred of these check dams have been constructed in this manner on the Stillwater project. Mr. Wheatley reports that nature has scoured its own stilling basin, and that no unsatisfactory results have been obtained thus far.

Design and Construction of Sodded Terrace Outlet Channels[1]

By Howard Matson[2]

SINCE no experimental field studies have been made under controlled runoff conditions to determine the limiting factors with respect to sodded terrace outlet channels, such as the optimum ratio of breadth to depth, the maximum allowable velocities and depths of water for various slopes and types of sod and for different durations and frequencies of flow, and the effect upon the roughness coefficient of variations in sod and weed growth, in setting up standards of design it is necessary to make certain assumptions. In the absence of reliable research data these assumptions must be based upon careful observation of existing channels. Bermuda grass is the only type of vegetative cover which has been used in outlet channels on the Duck Creek project, and since it is probably the most erosion-resistant grass adaptable to this region, it has been our aim to determine the probable limits of its application to channel control.

There are more than fifty sodded terrace outlet channels scattered throughout the Duck Creek watershed on slopes from 2 to 10 per cent and on widely differing soil types, from fine sand to a heavy impervious clay subsoil. Most of these channels have been inspected after each rain, and those which are accessible have been observed frequently during rains. Strips of sod 12 inches wide and spaced 4 feet apart on centers have been very effective on slopes up to and including 4 per cent, even on fine sand, and solid sod has shown no damage on slopes up to 10 per cent. In several channels runners from fertilized sod strips in subsoil attained a growth of as much as 42 inches in from five to six weeks.

At the meeting of engineers of the Soil Conservation Service held in Oklahoma City early last February, it was agreed that for lack of definite information 5 feet per second should be used as the maximum designed velocity in sodded channels, and all of our channels which are protected by sod alone have been designed on this basis. In channels protected by a combination of sodded intervals and semi-permanent rock and sod drops with masonry cut-off walls, surface velocities as high as 9 feet per second with an 8-inch depth of water have been observed for a duration of 10 minutes, with an average surface velocity of 6½ feet per second for 30 minutes. No apparent damage resulted from this flow.

The sodded channels designed for a maximum average velocity of 5 feet per second have shown a decided tendency toward silting, even when closely grazed, and during light rains the runoff water meanders from side to side in the channel around the silt deposits. Since Bermuda sod appears to be capable of withstanding much higher velocities than 5 feet per second, at least for short periods at infrequent intervals, it seems to be feasible and desirable to design sodded channels for a higher mean velocity.

Proceeding on this basis, I have prepared the accompanying table showing the theoretical depth of water and bed width of channel for various slopes and quantities of runoff at increments of 10 second-feet. For slopes of 6 to 10 per cent the cross section is designed for a maximum mean velocity of 8 feet per second to carry the probable runoff from the maximum rainfall intensity to be expected during a ten-year period.

The cross sections for 4 and 5 per cent have been designed for a maximum mean velocity of 7 feet per second, and for 6 feet per second at 3 per cent, in order to avoid having the excessive depth of water in the channel which would be necessary to produce a velocity of 8 feet per second.

These calculations are based on the Manning formula for the flow of water in open channels, which is

$$Q = \frac{1.486}{n} AR^{2/3} S_b^{\frac{1}{2}}$$

where Q = rate of flow in cubic feet per second

A = area of cross section of water in square feet

R = hydraulic radius, or A divided by "wetted perimeter," feet

S_b = slope of channel bed in per cent

n = value of "roughness coefficient" in the Manning formula, similar to Kutter's formula

v = velocity in feet per second.

Assuming that 0.04 is the correct roughness coefficient for sodded channels, it is possible to determine the cross section of a channel for a desired velocity and given slope by the following mathematical steps:

$$Q = \frac{1.486}{n} AR^{2/3} S_b^{\frac{1}{2}} \quad \text{[1]}$$

$$v = \frac{1.486}{n} R^{2/3} S_b^{\frac{1}{2}} \text{ (Dividing through by } A) \quad \text{[2]}$$

$$R^{2/3} = \frac{vn}{1.486\, S_b^{\frac{1}{2}}} \text{ (By transposing)}$$

[1]Paper presented at a meeting of the Southwest Section of the American Society of Agricultural Engineers at Tyler, Texas, July 10, 1935.

[2]Agricultural engineer, Duck Creek Project, Soil Conservation Service, U. S. Department of Agriculture.

CALCULATED DEPTH OF WATER AND BED WIDTH OF CHANNEL IN FEET
For Side Slopes of 1½ to 1

Slope of Channel in Per Cent	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
10	4.0	4.0	.73 4.1	.66 6.6	.64 8.9	.62 11.1	.61 13.4	.60 15.7	.59 18.0	.59 20.2						
9	4.0	4.0	4.0	.75 5.5	.71 7.7	.69 9.9	.68 12.0	.67 14.1	.67 16.1	.66 18.6	.66 20.2					
8	4.0	4.0	4.0	.88 4.4	.82 6.3	.79 8.4	.76 10.4	.74 12.3	.73 14.3	.73 16.2	.72 18.0	.71 20.0				
7	4.0	4.0	4.0	4.0	1.00 5.0	.91 7.0	.86 8.7	.85 10.6	.83 12.3	.82 14.1	.81 15.8	.80 17.5	.79 19.4			
6	4.0	4.0	4.0	4.0	4.0	1.08 5.1	1.01 7.0	.99 8.5	.97 10.1	.95 11.7	.93 13.3	.92 14.8	.91 16.4	.91 17.9	.90 19.4	
5	4.0	4.0	4.0	4.0	.96 5.7	.93 7.8	.90 9.7	.88 11.7	.87 13.5	.86 15.4	.85 17.3	.84 19.2	.83 21.0	.82 22.9	.81 24.7	.80 26.7
4	4.0	4.0	4.0	4.0	4.0	1.26 4.8	1.16 6.6	1.12 8.5	1.09 10.1	1.06 11.7	1.04 13.4	1.03 15.0	1.02 16.6	1.01 18.2	1.0 19.8	1.0 21.4
3	4.0	4.0	4.0	4.0	1.27 4.7	1.15 6.9	1.10 9.0	1.06 11.0	1.03 12.9	1.02 14.8	1.01 16.7	1.00 18.6	.99 20.6	.98 22.5	.97 24.3	.97 26.1

Runoff in Cubic Feet Per Second

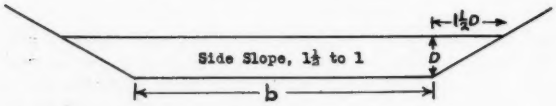
NOTE: For 6% slope inclusive, mean velocity = 8 ft. per second.
For 4% and 5% slopes, mean velocity = 7 ft. per second.
For 3% slope, mean velocity = 6 ft. per second.

$$R = \left(\frac{vn}{1.486\, S_b^{\frac{1}{2}}}\right)^{3/2} \quad [3]$$

Let P = wetted perimeter

b = bed width of channel in feet

D = depth of water in channel in feet.



For a channel with side slopes of 1½ to 1,

$$P = b + 2\sqrt{D^2 + (1.5D)^2}$$
$$= b + 2\sqrt{D^2 + 2.25D^2}$$
$$= b + 2\sqrt{3.25D^2}$$
$$= b + 2\,(1.8D) = b + 3.6D$$
$$b = P - 3.6D \quad [4]$$

Similarly

$$A = (b + 1.5D)D = Db + 1.5D^2 \quad [5]$$

Substituting the value of b shown in equation 4 for b in equation 5,

$$A = D\,(P - 3.6D) + 1.5D^2$$
$$= DP - 3.6D^2 + 1.5D^2 = DP - 2.1D^2$$
$$2.1D^2 - PD + A = 0 \text{ (Resolving into quadratic equation)} \quad [6]$$

The general formula for the solution of a quadratic equation is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad [7]$$

$x = D$ = depth of water

$a = 2.1$ = constant for channels with 1½ to 1 side slopes

$b = -P$ (varies with S_b, Q, and A)

$c = A$ (varies with Q for a given slope).

Substituting the values in equation 6 for the terms in equation 7,

$$D = \frac{-(-P) \pm \sqrt{(-P)^2 - (4 \times 2.1)\,A}}{2 \times 2.1} \quad [8]$$

$$D = \frac{P \pm \sqrt{(P^2 - 8.4A)}}{4.2} \quad [8]$$

For the purpose of illustration, let us assume that 100 cubic feet of water per second is to flow down a sodded channel on an 8 per cent slope at a mean velocity of 8 feet per second.

Substituting these values of v and S_b in equation 3, using $n = 0.04$,

$$R = \left(\frac{vn}{1.486\, S_b^{\frac{1}{2}}}\right)^{3/2}$$
$$= \left(\frac{8 \times .04}{1.486\sqrt{.08}}\right)^{3/2}$$
$$= 0.664$$

(NOTE: For convenience in the solution of Manning's formula, a column of values of the term $1.486\, S_b^{\frac{1}{2}}$ is given in Table III in "Diagrams for Use in Hydraulic Design of Erosion Control Structures," by H. L. Cook, hydraulic engineer, Soil Conservation Service.)

For conditions of uniform flow in an open channel, $Q = Av$. Since in this case $Q = 100$ and $v = 8$, $A = 100/8 = 12.5$ square feet, $P = A/R$, and R has been determined as 0.664. Therefore, $P = 12.5/0.664 = 18.8$ feet, and the only unknown factors remaining are the depth and bed width of the water cross section.

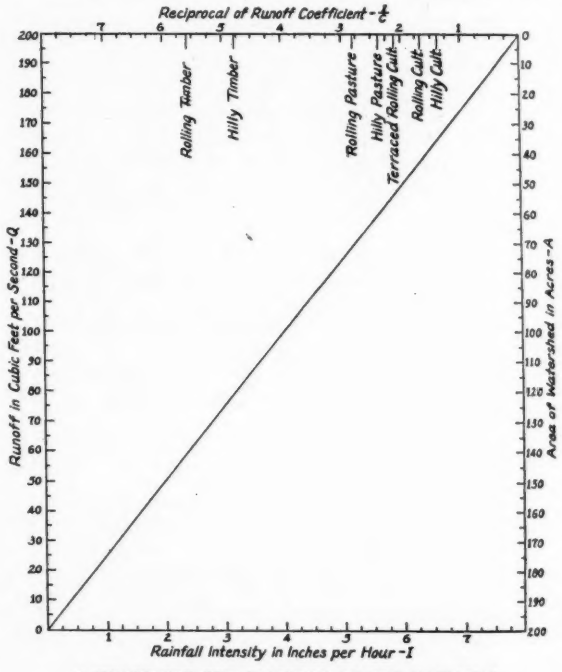
Since the wetted perimeter has been found to be 18.8 feet, the depth, D, may be obtained by substituting this value of P in equation 8.

$$D = \frac{P \pm \sqrt{(P^2 - 8.4A)}}{4.2}$$
$$= \frac{18.8 \pm \sqrt{(18.8)^2 - (8.4 \times 12.5)}}{4.2}$$
$$= 0.725 \text{ feet} = 8\text{-}11/16 \text{ inches}$$

To obtain b, this value of D may now be substituted in equation 4

$$b = P - 3.6D$$
$$= 18.8 - (3.6 \times .725)$$
$$= 16.2 \text{ feet.}$$

(Continued on page 330)


Reciprocal of Runoff Coefficient - 1/C
Rolling Timber
Hilly Timber
Rolling Pasture
Hilly Pasture
Terraced Rolling Cult.
Rolling Cult.
Hilly Cult.
Runoff in Cubic Feet per Second - Q
Area of Watershed in Acres - A
Rainfall Intensity in Inches per Hour - I

A CHART FOR THE SOLUTION OF THE RATIONAL RUNOFF FORMULA

For the determination of runoff from any given area, first determine the intensity of rainfall for the period of concentration of watershed in question. A straight-edge is laid upon the chart, connecting the proper value of I upon the lower axis with the proper notation of characteristics of watershed upon the upper horizontal axis. The straight-edge will intersect the diagonal in a point. If the position of the straight-edge then be changed in order that it will pass through the point just determined on the diagonal and the point upon the right-hand vertical axis denoting the area of the watershed, the proper value of the runoff cubic feet per second may be read from the left-hand vertical axis at the point of its intersection with the straight-edge. (NOTE: This chart is an adaptation of the one appearing on page 13 of the January 1935 AGRICULTURAL ENGINEERING, prepared by Mr. Garrett B. Drummond.)

A New Method of Obtaining Dust for Testing Tractor Air Cleaners[1]

By F. A. Brooks[2]

EXCESSIVE WEAR in tractor engines caused by dust even in spite of air-cleaning equipment led to the initiation of the air-cleaner project at the California Agricultural Experiment Station in 1921. Evidently some types of air cleaners furnished with tractors were practically useless, and apparently none were fully effective in protecting the engine against the dust encountered in California.

The dust protection afforded in 1922, when the first test results were published, can be estimated on the basis of the total number and horsepower of the tractors, in use at that time, equipped with each kind of air cleaner. One can then determine what proportion of the total installed horsepower is affected by the efficiency of each cleaner; and by taking the summation of each power group multiplied by its cleaner efficiency one obtains a figure that represents the per cent protection afforded all the farm tractors by the various air cleaners in use at that time. This calculation, based on rough estimates of tractor models in use in California in 1922, shows a weighted average protection of 75 per cent. The same method of estimation applied to the 1932 lists gives 95 per cent.

These efficiency figures are based upon tests of air cleaners which had been properly serviced; they therefore represent a maximum protection not obtained in the field. The 1922 figure, furthermore, would have been lower if the finer test dust of 1932 had been used; consequently, there can be no question of the great improvement in ten years' time.

That this rapid change should be attributed largely to the research work in this project can be seen readily in the correspondence with all air-cleaner manufacturers. One manufacturer, for example, complained that the wrong model air cleaner was reported, while as a matter of record his new model was made only after he had obtained the test results he wished suppressed. The many compliments, however, which were paid Professor A. H. Hoffman for his forthright presentation of all tests with explicit names, model numbers, and manufacturers' addresses fully justified his procedure.

Although it is not practicable to interpret air-cleaner efficiency directly in terms of savings in repair costs, recorded examples showed the imperative need of efficient air cleaners. An engineer of a large tractor manufacturing company has stated that their latest model tractor would run in dusty conditions under full load for 3,000 hours with no adjustments whatever, and for 6,000 hours with only minor adjustments, *provided it had a satisfactory air cleaner;* but that without an air cleaner the engine would be ruined in 15 hours' use.

The amount of improvement in air-cleaner design still possible is not easy to gauge, for most serious complaints now concern operations under extreme conditions when the best air cleaners fail to function satisfactorily, or concern the laborious servicing requirements that cannot always be performed properly during continuous usage of equipment. Critical study indicates, however, that major improvements are still needed. The constant air-flow rate for governed Diesel engines invites the application of Cyclone separators to reduce the servicing requirements of the regular wet-surface filters. It also seems evident that some method can be devised for making practical the use of the simple and excellent filter-cloth type air cleaners which are not used because of occasional difficulty with high restriction when dust and fog are encountered simultaneously.

Review of Technical Criticisms

The correspondence and experimental data developed through this project for the past ten years show that all adverse criticisms are directed at the limitations of the test methods; there is almost universal praise of Professor Hoffman's work within these limitations. It therefore appears advisable to consider in detail the objections raised as to apparatus and test limitations:

1 Dust was too fine
2 Dust was fed into the test cleaner too rapidly
3 Laboratory test with fixed mounting of cleaner did not represent field conditions.

The explanations on these three points are as follows:

1 Coarse dust is not difficult to exclude from engines. The dust adopted as standard is a mixture of several samples collected in various parts of California where the dust problem is serious for automotive equipment. It therefore represents fairly a real condition, though not an average one. Furthermore, any cleaner not able to cope with the fine dust cannot be considered satisfactory for California use. A trial test in May, 1935, with a good Diesel tractor air cleaner showed a variation in efficiency from 94 per cent to 74 per cent simply with different particle-size dust. It is to be noted that where only 6 per cent standard dust passed through, 26 per cent of extra fine was not caught.

2 The rate of feeding dust into a cleaner had to be faster than under ordinary operating conditions in order to keep the time required for testing within a reasonable limit. This procedure admittedly was disadvantageous to all oily type cleaners which depend upon the slow capillary movement of oil to keep the dust-catching surfaces moist. The average rate of feed of about ⅓ pound per hour is, however, much less than obtained in the field under extreme dust conditions.

3 It was necessary to have fixed laboratory test conditions to make the test results of different cleaners comparable. Field tests were made to observe operating characteristics of individual cleaners, but the data could not be used to compare different cleaners, because of uncontrollable change of conditions.

On the whole there is no valid criticism of these assumed limitations as far as the user of air cleaners is concerned, but it is evident that they would not give a fully correct picture of the characteristics of various cleaners.

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[1]Revised paper presented at a meeting of the Pacific Coast Section of the American Society of Agricultural Engineers, Corvallis, Oregon, December 28 and 29, 1934.

[2]Associate agricultural engineer, California Agricultural Experiment Station. Mem. ASAE.

Hoffman's work did force a great improvement, and for this very reason the problems now to be considered are different from those that caused the initiation of the project.

Review of Test Objectives

The objectives set up at the initiation of this project are not in need of alteration. Slight revision yields the following outline:

Primary Objectives:

1 Efficiency in removing dust from the air stream
2 Restriction to air flow.

These two objectives are subject to many different conditions, of which the following are considered the main variables:

Variable Conditions:

1 Air-flow range from idling to maximum
2 Dust composition (particle size and nature)
3 Cleaner condition—newly serviced or in need of servicing
4 Cleaner mounting — fixed or jolting, straight or tipped
5 Liquid level.

No comprehensive study has yet been made of the effect of any of these variable conditions.

Incidental Observations:

1 Service requirement (fill-up test, chaff, and coarse dust)
2 The effect of loose or damaged connections
3 Loss of maximum power because of restriction in air flow.

One test in 1933 developed into a modified series run covering the effect of variable air flow and interrupted dust feed on a simple oil-bath cleaner. Fig. 1 shows clearly how these variables affect the restriction and explains why this cleaner with an excellent record on trucks is not satisfactory for tractors exposed to dust continuously and operating at nearly constant power.

Another cleaner using forced oil circulation independent of the engine speed was naturally unaffected by interruption of dust feeding, but still showed poor efficiency with the standard test dust in comparison with the dust used by the maker. Simple laboratory changes in the screening raised the efficiency for fine dust to the 95 per cent expected from good oil-bath cleaners.

A few such tests showed that we could not expect to get a complete picture of air-cleaner performance until we could make comprehensive series tests including various particle-size dusts. It seemed reasonable to expect that every air cleaner would show definite characteristics and efficiency, varying with at least three operating factors: (1) dust-particle size, (2) quantity of dust handled since servicing, and (3) air flow.

The first requirement for such comprehensive test series is a large quantity of standardized dust whose particles are fine enough to simulate natural dust conditions encountered in agricultural operations with tractors in California.

Dust Needed for Tractor Air-Cleaner Tests

Field operations with tractors involve the most serious dust problems, and it is to be expected that the composition of the dust raised bears some relation to the nature and condition of the soil. Soil surveys like those shown in Table 1 for the Woodland, California, area[3] indicate quite plainly the large portion of fine particles to be found in good agricultural land. Large areas of each of these soil types are under cultivation. The larger particles of each soil type are relatively unimportant sources of dust because the smaller particles are so much more easily raised into dust clouds. The long, dry summers in California favor deflocculation of fine aggregates and tend to produce finer dust than would occur from the same soil under more humid conditions.

TABLE 1. MECHANICAL ANALYSES OF YOLO SOILS

	Fine gravel 2.0-1.0 mm	Coarse sand 1.0-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Silt 0.05-0.005	Clay <0.005
Loam	0.1%	0.4%	0.9%	9.5%	27.3%	43.3%	18.2%
Silt loam	0.0	0.1	0.1	1.2	5.0	69.1	24.4
Clay loam	0.0	1.9	3.9	16.6	16.6	42.1	19.0
Silty clay	0.0	0.1	0.1	3.2	5.0	58.3	33.5
Clay	0.0	0.1	0.1	0.9	7.6	50.9	40.4

The 5-micron particle, the smallest silt particle, would fall nearly 5 inches per minute. Obviously, then, clouds of dust drifting away from a field implement and existing more than ten minutes must be composed of the clay particles. Since the 2-micron size (0.00008 inches) dividing the coarse clay from colloidal or ultra-clay would settle at a rate of approximately 4 feet per hour, dust clouds lasting for an hour must be made up largely of particles of colloidal size. The size distribution of fine commercial fillers may be judged by the figures given for ocher[4] showing 71 per cent in the silt and 21 per cent in the clay groups. Evidently this material, predominantly of silt particles, would be suitable to test cleaners subject only to coarse dust that vanishes in less than ten minutes. Under usual California conditions the dust clouds rarely settle so rapidly, and as the inexpensive commercial fillers would not give the desired particle-size groups, we saw no alternative to making our own test dust.

Selection of Apparatus for Grading Dust

Inquiry of the Division of Soil Technology, College of Agriculture, University of California, revealed that it would cost about ten dollars to obtain a half-day supply of dust if the analytical centrifuge method were used. Even if this cost could be reduced, the method was questionable because the deflocculating agent used changed the nature of the dry soil.

[3]Mann, Warner, Westover, and Ferguson. Soil survey of the Woodland Area, California. U. S. Department of Agriculture, Bureau of Soils, p. 27-32. 1911.

[4]Weigel, W. M. Size and character of grains of non-metallic mineral fillers. U. S. Department of the Interior, Bureau of Mines, Technical Paper 296: 32-35. 1924.

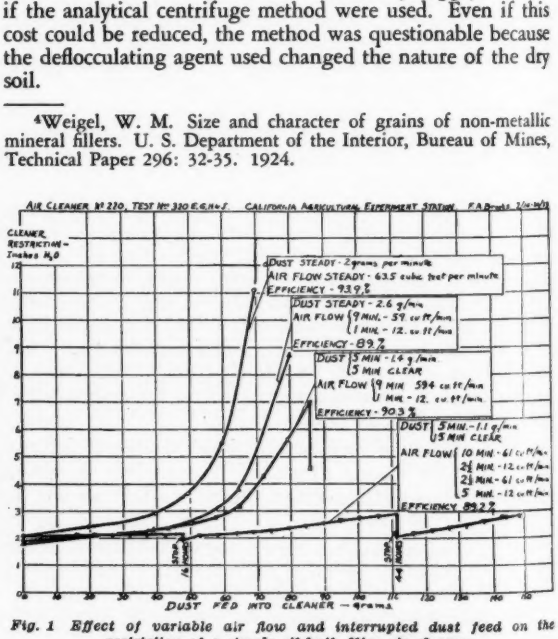
AIR CLEANER Nº 220, TEST Nº 320 E.G.H.+F. CALIFORNIA AGRICULTURAL EXPERIMENT STATION F.A.D.-W.S. 2/24/33
CLEANER RESTRICTION - Inches H2O
DUST STEADY - 2 grams per minute
AIR FLOW STEADY - 63.5 cubic feet per minute
EFFICIENCY - 93.9%
DUST STEADY - 2.6 g/min
AIR FLOW 9 MIN. - 59 cu ft/min
1 MIN. - 12. cu ft/min
EFFICIENCY - 89.2%
DUST 5 MIN - 2.6 g/min
5 MIN CLEAR
AIR FLOW 9 MIN 59.4 cu ft/min
1 MIN - 12. cu ft/min
EFFICIENCY - 90.3%
DUST 5 MIN. - 1.1 g/min
5 MIN CLEAR
AIR FLOW 10 MIN - 61 cu ft/min
2½ MIN - 12 cu ft/min
2½ MIN - 61 cu ft/min
5 MIN - 12 cu ft/min
EFFICIENCY 89.2%
STOP 76 HOURS
STOP 44 HOURS
DUST FED INTO CLEANER - grams

Fig. 1 Effect of variable air flow and interrupted dust feed on the restriction of a simple oil-bath-filter air cleaner

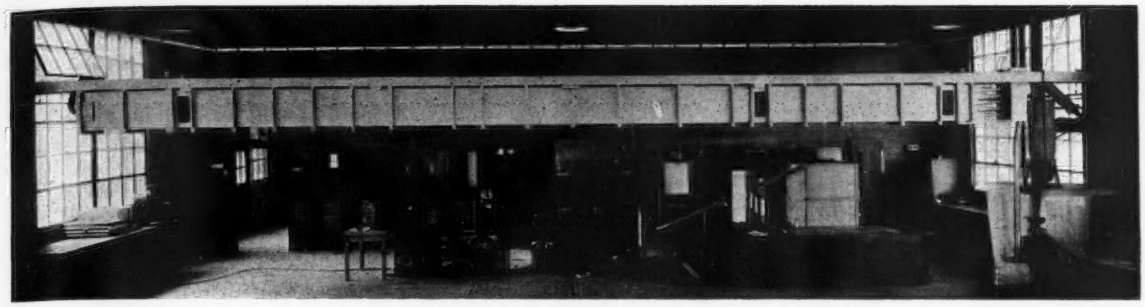

Fig. 2 Horizontal air-flow sedimentation chamber for grading dust

The air elutriator developed by Mr. Roller[5] at the U. S. Bureau of Mines was considered a satisfactory method of grading dust, but too slow because of the necessity for blowing the dust repeatedly to get adequate separation. For obtaining large quantities of dust of definite particle size, the limitations for analysis of small samples could be disregarded, so the air-elutriator method was studied for modifications to obtain separation in one pass through each tube and to make the operation continuous. The rate of rise of dust-laden air might be made more uniform if the dust stream were surrounded by clear air moving at the same rate. The dust carried over from one chamber might be introduced into succeeding chambers with slower and slower vertical air flow to separate smaller and smaller particles. However, the cross-sectional area of the chamber required for the 5-micron separation, at the rate of dust feed desired, would be about 100 square feet, and the height would be impossible for the laboratory.

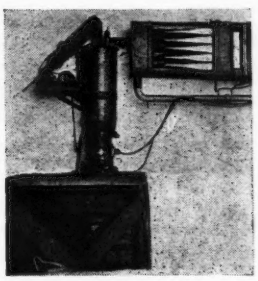

Fig. 3 Dust-supply head

Such considerations led at once to the design of a horizontal air-flow chamber wherein the silt-size particles should settle to the floor after traveling various distances, according to their size, while the lighter clay particles floated on into a filter screen. This involves an irreconcilable conflict in physical principles, in that the dust particles are expected to settle out from a heavy stream of dust-laden air down through a parallel stream of clear air of less total density, while the entire air flow remains laminar. The column of air introducing the dust might be made lighter by extra warming, but as soon as the dust began to settle out of this warm stream the inherent instability would return. This phenomenon can be illustrated by a drop of ink in still water. At first the drop settles rapidly; then almost stops while mushrooming to ring form. Next, several smaller jets sink rapidly into the clear water, again mushrooming out until dispersion is obtained. Finally, the settling proceeds slowly in accord with Stokes' law.

Professor Hoffman had obtained significant separation of dust used by various air-cleaner manufacturers, by floating the dust fully dispersed through a 6-inch pipe 30 feet long. The horizontal air flow most nearly approached natural conditions, therefore in spite of the physical conflict a horizontal flow chamber was built.

Horizontal Air-Flow Chamber

Before building the flow chamber Dr. Th. von Karman, director of the Guggenheim Aeronautics Laboratory, California Institute of Technology, was consulted and specified the following conditions for obtaining smooth laminar air flow:

1. Rate of flow, judged by Reynolds number, must be in the viscous region
2. The flow chamber must have no leaks
3. There must be no thermal disturbance
4. Any increase in the flow area must be so gradual that the increase in pressure head is less than the friction loss; that is, the pressure gradient must never rise in the direction of flow.

The first condition for viscous flow determined the maximum velocity for whatever size channel was adopted. A rectangular section with a width two-thirds the depth was chosen to obstruct large rotational eddies. A size of 12 by 18 inches inside was chosen arbitrarily as a compromise between the advantage of considerable depth for gravity separation and the disadvantage of less stability in the very slow rate of flow. The positive viscous flow indicated by a Reynolds number of 1000 is obtained with an average linear velocity of 8 feet per minute, but a speed of 14 feet per minute has been found possible before indications of turbulent flow appear.

The second condition for an air-tight chamber did not seem difficult; and to meet the third condition without thermal insulation we built the first chamber of ¼-inch plywood instead of metal. Unfortunately, this construction

[5]Roller, Paul S. Separation and size distribution of microscopic particles. U. S. Department of Commerce, Bureau of Mines, Tech. Paper 470. Further details given in "Industrial and Engineering Chemistry," 4(3): 341. 1932.

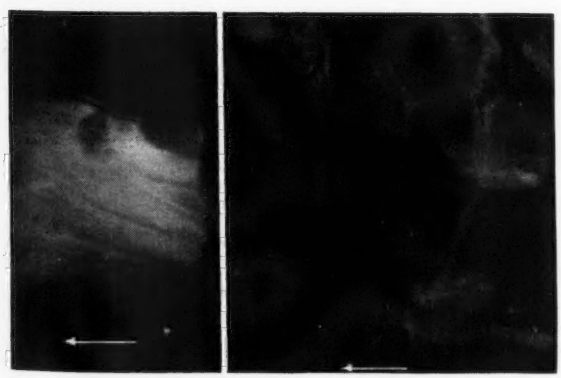

Fig. 4 (Left) Dust stream entering with disturbance due to small air leak in sedimentation chamber wall. Fig. 5 (Right) Inverted mushroom settling of dust in moving air column

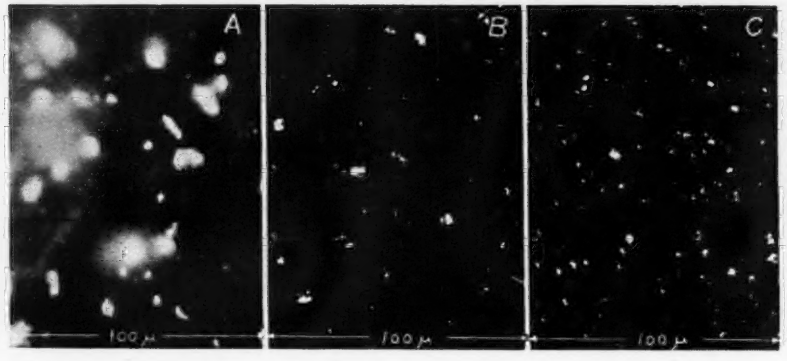

Fig. 6 (A) Photomicrograph of dust sample drawn at entrance to sedimentation chamber while flow was stopped. Focused on small particles. (B) Photomicrograph of dust taken from 10 feet down stream, chamber in operation 3 hours. (C) Photomicrograph of dust taken at end of chamber (36-foot run)

gave a great deal of trouble, which was finally traced to small leaks that continued to appear in spite of painting.

The fourth condition for falling pressure gradient forced us to abandon the idea of an expanding chamber, which was attractive as a means of shortening the length of run required to settle particles of 5 microns diameter.

The new sedimentation chamber (Fig. 2) is built of 1¼-inch, full-width Ponderosa pine boards; Nos. 1 and 2 clears, with all joints splined and glued. The straight run is 36 feet long, is framed with oak and is painted both inside and outside. The filter cloth screen used at the discharge end to intercept all dust particles smaller than 5 microns in diameter, is in a deep V to offer extended surface, and the cloth is vertical to permit shaking off the dust without disassembling. These complications were found necessary, because the dust is not evenly dispersed in the air stream, and the upper or lower part of the screen may fill up first, forcing the air stream out of a straight laminar flow toward the more pervious area.

To collect the particles of various sizes from different parts of the chamber floor, three removable floor sections are provided giving direct access to the entire chamber, the dust being collected by rubber scrapers.

To introduce the dust and clear air at the head of the chamber the apparatus shown in Fig. 3 has been developed from unsatisfactory simpler devices. The entrance to the straight run has a honeycomb, and the entire cross-sectional area is divided into fifteen equal sections with the air flow to each under manual control. The dust stream is introduced into the center row second from the top, so that it is completely surrounded by clear air, and the lowest dust particle starts about 12 inches above the floor.

The dust is mixed with air in a vertical chamber 13 inches in diameter equipped with a 2-hp agitator in accordance with the design of the Western Precipitation Company for reducing the specific gravity of small particles. The high-powered mixing is necessary to break down the flocculated clay particles.

The feeding of dust into the air-tight mixing chamber presented another serious difficulty, but can now be considered reasonably satisfactory. The revolving cylinder with rising bottom of the Cole top delivery fertilizer distributor served as a type pattern, which was modified to provide automatic dust feed for 20 hours at a rate of about 1⅓ grams per minute. The 45-degree angle to clear the top of the mixing chamber has proved too large, in that some tumbling now occurs.

The dust stream from the mixing chamber entering the horizontal air-flow chamber is very easily disturbed. Fig. 4 shows the entering dust stream with a disturbance that was finally traced to a leak caused by shrinking of wood near the 500-watt lamp used for illuminating the dust. The motion is so slow that one easily follows individual dust particles by eye and is tempted to complain about the departure from straight-line travel until one has observed the floating of a single silk fiber attached to the straightener vanes. In free, calm air such threads are all but invisible and wave and bend in an uncontrollable manner, whereas in the chamber they act like cast-iron flap valves.

The jet disturbances of undetectable leaks in the flow chamber were finally avoided by raising the air pressure in the chamber to slightly above atmospheric pressure. The leaks were then outward and had a very limited local effect. This simple expedient immediately established such a stable laminar flow that the same inverted mushroom vortices found in the quiet ink-drop experiment reappeared in the moving air stream as shown in Fig. 5.

CONCLUSION

The photomicrographs of the dust settling in the chamber show the first results from this new dust-grading apparatus. In all cases the width of the field is drawn at 0.1 mm, or 100 microns. All the pictures were obtained with a 40X dry Zeiss apochromatic objective and with the Homal III photographic ocular, dark field illumination being used.

Fig. 6 (A) shows the dust as introduced. The slide was made by aspirating through a 50-mm tube for 15 minutes from the chamber at the head end after the flow was stopped and while the dust eddied back in large circles. Being focused for the small particles, it shows a great number below 1 micron in diameter. Very little flocculation is evident. Observations focused 5 microns above the plane of the photograph show many particles of silt size, while focusing 10 microns above shows the existence of many thick particles whose larger flat diameter may indicate flocculation.

Fig. 6 (B) shows the particles taken 10 feet down stream after the flow chamber had been in operation 3 hours. There are few 1-micron particles, but some evidence of flocculation; and, of course, there are a large number of single crystals in the silt group.

Fig. 6 (C) shows the particles taken at the end of the 36-foot run. There are innumerable fine particles, but in addition one can see a few silt particles that probably should have settled earlier and some very small flocculated groups that may be due to the method of sampling. The slides for Figs. 6 (B) and 6 (C) were obtained by direct exposure from a rotary cartridge holder.

No statistical study of particle size has yet been made, but the classification of dust evidently is satisfactory for air-cleaner test purposes. A new series of air-cleaner tests with the different dust-particle size groups is, therefore, now possible and will be undertaken in the near future.

Agricultural Engineering Digest

A review of current literature by R. W. TRULLINGER, senior agricultural engineer, Office of Experiment Stations, U. S. Department of Agriculture.

APPLICATION OF STEAM IN THE STERILIZATION OF SOILS, *A. H. Senner.* U. S. Dept. Agr., Tech. Bul. 443 (1934), pp. 20, figs. 5. A description of common methods of steam sterilization of soils and of the physical principles involved in steam sterilization is followed by an account of an investigation the objects of which were to determine the effect of initial steam pressure on the final moisture content of the soil, the final temperature of the soil, the quantity of steam needed, and the effect of the available horsepower on the task of soil sterilization. The tests were conducted out of doors on a plat of selected soil consisting of a brown fine sandy loam mixed with well-rotted horse manure, so as to approximate a soil frequently found in greenhouses.

The results showed that it is not possible to obtain a soil temperature in excess of about 212 deg F without the use of superheated steam. The moisture content of the soil increases during sterilization, but the increase is not materially affected by variations in steam pressure. Increasing the initial steam pressure does not decrease the quantity of steam required to sterilize the soil. The pressure of the steam under the pans remains constant at the various boiler horsepowers due to heaving of the pan and increased escape of steam into the air as the boiler horsepower is increased. The pressure in the tile increases as the boiler horsepower is increased.

With the tile method roughly 1 sq yd of soil may be sterilized per boiler horsepower. With the pan method 3 sq ft per boiler horsepower may be sterilized. About 2 lb of coal are required per square foot of soil surface with both the tile and pan methods. The capacity of a steam heating main is greatly increased when used to convey steam for sterilization because of the absence of appreciable back pressure.

PROPER SPACING AND DEPTH OF TILE DRAINS DETERMINED BY THE PHYSICAL PROPERTIES OF THE SOIL, *J. H. Neal.* Minnesota Sta. Tech. Bul. 101 (1934), pp. 62, figs. 30. A study is reported of four tile drainage systems in different parts of Minnesota where there is a wide variation in soil type. There was also a variation in spacing at each of the stations and a variation in depth as between the stations. Studies were made of the fluctuations of the ground water caused by precipitation at each of the stations over a period of 4 yr and the results correlated with the physical properties of the soils.

The soils included shallow, well-decomposed woody peat overlying a yellowish-gray to gray sand or very sandy loam, a light-brown silty clay loam overlying 30 in of gray silty loam containing less organic matter, a soil varying from a muck 6 in in depth to a well-decomposed peat 2 ft in depth overlying a stratum of mucky clay from 6 to 12 in in depth, and a light-brown heavy silt loam overlying gray boulder clay.

The results show that in northern latitudes where the ground remains frozen all winter the winter precipitation can usually be disregarded as far as the design of the tile system is concerned, because the snow melts in the spring and runs off over the surface before the ground thaws.

About one-half of the rainfall from March 1 to October 31 occurs in rains of less than 1 in, one-fourth in rains of 1 to 1.99 in, and one-fourth in rains of 2 in or more. In terms of the number of storms, less than 1 in falls during 82 per cent of the storms, 1 to 1.99 in fall during 12 per cent, and 2 in or more fall during 6 per cent of the storms. As there is an average of 30 storms per season (March 1 to October 31), there would be an average of less than 2 storms per year when 2 in or more fell in 24 hr.

Little or no flow occurs through the tile drains after a rain if there has been less than 3 in of rain in the previous month. Practically all rains of more than 1 in when preceded by 3 in or more in the previous month cause run-off. Rains of less than 1 in occurring during the growing season (May 1 to August 31) are not likely to cause run-off through tile lines, unless they are preceded by 4 in or more during the previous month. As a general rule, the percentage of run-off is less for the larger than for the smaller rains which cause run-off, and is less during the growing season than for early and late rains, since the growing crops exert a noticeable influence upon the amount of run-off. The maximum run-off usually occurs during the first 6 hr after the heavy part of the storm and may exceed a rate of 1 acre-inch per day if the system will carry it. Where there are surface inlets to the tile line the time of concentration is less than 6 hr.

Following a dry period of from 2 to 4 weeks during the growing season, it takes several inches of rain to bring the soil to its maximum capillary capacity. Until this point is reached there will be no fluctuation of the water table and consequently no action by a tile drainage system. After the capillary capacity is reached, the ground water table rises rapidly during a storm but subsides very much more slowly, the rate of drop being an exponential function of both the hydraulic slope and the tile spacing, as indicated by the following equations:

$R_d = 0.165\ S^{3.4}$ in which R_d is the rate of drop midway between tile lines in feet per day. S is the hydraulic slope expressed as feet of head of the ground water surface above the tile per 100 ft distance from the tile lines. $R_d = K\ (T_s)^{-0.7}$. R_d is the rate of drop. K is a drainage factor depending upon the hydraulic slope and the type of soil, and T_s is the tile spacing in feet.

The rate of drop is much faster during the growing season than for early spring and late fall rains, owing to the combined action of heavy transpiration and tile drainage when it exists. The proper spacing and depth of tile lines is dependent upon three important factors, namely, (1) the type of soil, (2) the types of crops grown, and (3) the climatic conditions. The observations indicate that the crops were not seriously injured if the water table was held at least 6 in below the surface and was lowered at the rate of 1 ft per day through the second 6-in depth interval and at the rate of 0.7 ft per day through the third 6-in depth interval.

Spacing and depth of tile lines is an exponential function of some physical property of the soil as, for example, (1) the moisture equivalent, (2) the plasticity, and (3) the percentage of clay. This functional relationship to the moisture equivalent is shown in the following equations:

$$T_s = \frac{12{,}000}{(M_e)^{1.6}}$$

$$T_s = \frac{10{,}000}{(M_e)^{1.55}}$$

$$T_d = \frac{17.5}{(M_e)^{0.5}}$$

T_s = the tile spacing in feet, T_d = tile depth in feet, and M_e = moisture equivalent.

The general conclusion is drawn that the effectiveness of a tile drainage system as a protection for, and a stimulant of, crop growth is manifestly dependent on the rate of drop of the water table at the midpoint between the drains. This rate of drop is dependent on the texture and moisture condition of the soil when well drained and on the depth and spacing of the tile drains, and both rate of drop and depth and spacing of tile drains are definite functions of the moisture equivalent, the plasticity, or the clay content of the soil under consideration.

Before the method of tile drainage design herein presented can be considered complete, it is considered probable that these equations should be checked under a wider variety of soil and climatic conditions.

COLUMBIA MANUAL OF CONCRETE CURING. Barberton, Ohio: Columbia Alkali Corp., 1934, pp. 55, figs. 19. This is a handbook of information on the curing of concrete.

MODERNIZING THE KANSAS HOME, *H. E. Wichers.* Kans. Engin. Expt. Sta. Bul. 32 (1934), pp. 133, figs. 94. The purpose of this bulletin is to present information on the modernizing of homes. Data are presented on present-day trends in home design, construction, and on methods of solving the modernizing problem.

THE ACTION OF WATER ON LEAD WITH SPECIAL REFERENCE TO THE SUPPLY OF DRINKING WATER, *H. Ingleson.* [Gt. Brit.] Dept. Sci. and Indus. Res., Water Pollut. Res., Tech. Paper 4 (1934), pp. VX + 115. This is a summary of existing knowledge on the subject. In addition to brief descriptions of the work of previous investigators, sections are included dealing with lead poisoning from drinking water in different parts of the world and the protective measures adopted. *(Continued on page 330)*

NEWS

Washington News Letter

THE following news of interest to the engineering profession is from the July 15 news letter of American Engineering Council, which represents national, state, and local engineering societies in Washington:

The clash between principle and method continues to make each day a lively one in Washington. The general situation with regard to the allotment of funds for engineering projects under work relief has not changed. The general trend is toward small work relief projects. Many of the large state projects are being broken down into small projects. Each state is a unit by itself in relation to the procurement of funds, and some progress is being made by those states which are aggressively organized to secure funds.

Under the plan of insuring loans for industrial rehabilitation, the possibilities of plant modernization are being pushed by the Federal Housing Administration. Our understanding is that there are many applications involving engineering improvements in machinery and equipment.

Comparatively few positions are expected to develop in Washington, but much activity is expected in the states under the direction of state administrators of the Works Progress Administration. State organizations are being formed now and engineers seeking employment should contact the state administrators of the Works Progress Administration.

Instructions to the state administrators tell them not to engage in or make use of politics in connection with execution of the work relief program, but appointments and assignments indicate that political sponsorship in the state may be as necessary as similar approval in Washington.

Engineers serving in administrative, consulting, professional, and supervisory capacities will be paid salaries and fees slightly less than those prevailing in the area where they are employed.

The Cooperative Survey of the Engineering Profession was an assured success when the final deadline for receipt of questionnaires fell on July 8. As this is written, it is impossible to arrive at the exact number of blanks received. Some will have to be weeded out because they come from men not properly qualified as engineers. But the number is ample to provide a good cross section of the engineering fraternity and to chart its situation through the depression years.

Plans for the final tabulation are reported in an article appearing in the July number of *Civil Engineering*, quoted in part as follows:

"While the exact details are not finally settled, it can be said in general that all the information in the questionnaire will be transferred to punched tabulating cards. The Bureau of Labor Statistics has devised code systems by which this information can be recorded by punching on a card 3¼x7¼ in. Once punched, the cards are fed through sorting machines, which can be set to count any particular item desired. Correlations can be established at will, such as 'How many civil engineers, graduates of a college with a bachelor's degree, are employed by municipal governments?'; or 'How many mechanical engineers working for the government are under civil service?' The Bureau is planning a series of such correlations according to states, and is selecting for the first tabulations the correlations which could be of the most immediate value. There is considerable congestion at the Bureau because of the great demand for statistics on other employment situations, but it is now anticipated that the results should be available early this fall.

"One very interesting fact regarding the individual questionnaire is that almost all engineers signed their names, thus enabling apparent discrepancies to be straightened out and other necessary editorial work to be done by correspondence. The questionnaires received to date have been completely filled out, and it is anticipated that the resulting statistics will be authoritative."

Council's inquiries as to the participation of engineering societies in public affairs have produced many interesting letters and suggestions which are helping in the compilation of a record of experience in this important field. Among the published accounts which have been called to our attention is a study of the number of engineers who are prominent in public life outside their professional work. This was reported in the April issue of *"Mechanical Engineering"* by Allan R. Cullimore, president of the Newark College of Engineering.

According to his findings, out of the 19,000 engineers listed in "Who's Who in Engineering," 1,600 appear among the 31,000 names in "Who's Who in America." Only about 250 are found to have figured prominently in non-technical pursuits—only about one engineer in a thousand. We inquired as to the basis of estimate and found that even this small ratio includes a liberal allowance for those who may have done eminent non-professional work which did not show up in "Who's Who."

Various explanations are offered as to the reason why engineers, having made an inestimable contribution to the general welfare in their technical work as individuals or as a profession, do not appear more in the general field of public affairs. The system of public affairs committee which Council is developing, together with the more aggressive action of engineering societies through the country, may tend to establish natural channels whereby engineers will be drawn into public matters with the aid of their colleagues, rather than fighting their way as individuals without help, encouragement, or objectives other than their own.

"The Formation of Capital," a new study by the Brookings Institution, completes the triology begun in "America's Capacity to Produce" and "America's Capacity to Consume," the findings of which are correlated and given added significance when viewed in their relation to the capital structure. As with the earlier reports, this study has been summarized in a pamphlet by the Maurice and Laura Falk Foundation of Pittsburgh.

A study of business cycles has been reported in the July 1 bulletin of the National Bureau of Economic Research, 1819 Broadway, New York (price 50c). This analysis seeks to make use of the improved and extended accumulation of statistical data in recent years, in revising past theories of cyclical behavior.

INTIMATE GLIMPSES OF RECIPIENTS OF AWARDS OF MERIT AT THE 1935 ASAE ANNUAL MEETING

(Left) Mr. and Mrs. Theo. Brown happily admire the 1935 Cyrus Hall McCormick Gold Medal awarded by the American Society of Agricultural Engineers to Mr. Brown "For Exceptional and Meritorious Engineering Achievement in Agriculture." (Middle, left to right) Colonel Oliver B. Zimmerman, who was given much deserved recognition by election as an Honorary Member of ASAE; Theo. Brown, the McCormick medallist; J. C. Tillman, who received the Farm Equipment Institute Cup awarded for the first time by the Society to the Georgia Student Branch of ASAE; Glen W. McCuen, president of the Society from June 1934 to June 1935. (Right) The last act of President McCuen in transfering the duties of office to his successor, Lawrence F. Livingston

To Attend Congress

E. R. GROSS, professor of agricultural engineering, Rutgers University, and Mrs. Gross, will attend the Second International Congress of Rural Engineering at Madrid, Spain, in September. Mr. Gross is scheduled to present a paper before the Congress, entitled "Sweet Potato Storages in New Jersey."

Successful Students' Meeting at Athens

Reported by James B. Stere

THE MEETING of the National Student Branch of the American Society of Agricultural Engineers, which was held during the 29th annual meeting of the Society at Athens, Georgia, in June, had the largest attendance and was one of the most successful meetings of the agricultural engineering students ever sponsored by that group. A total of 39 students were registered, a third of which were students in agricultural engineering from the University of Georgia. The other states represented in this registration were Illinois, Iowa, Minnesota, Missouri, Nebraska, Ohio, Pennsylvania, South Carolina, and Texas.

The three sessions of the meeting were presided over by Lester Malkerson, president of the National Student Branch for the year 1934-35.

At the opening session on Monday, June 17, the group was greeted by R. H. Driftmier, head of the agricultural engineering department at the University of Georgia and chairman of the committee on local arrangements for the annual meeting, and by Glen W. McCuen, President of the Society. This was followed by talks by Leonard J. Fletcher, agricultural engineer, Caterpillar Tractor Company, on "Selecting the Job"; by Fred A. Wirt, agricultural engineer, J. I. Case Company, on "Opportunities in Selling Farm Equipment"; and by A. W. Turner, International Harvester Company, on "What Industrial Concerns Expect of Graduates."

At the second session held Wednesday forenoon, July 19, the group listened to two very interesting technical talks, one, entitled "A Few Building Facts on Temperature Control," by Chas. P. Tobin, farm department, The Celotex Company, and the other on the subject "Concrete Work on the Farm," by Hugh R. Roberts of the Atlanta, Georgia, district office of the Portland Cement Association.

The last session of the group was featured by a report by Charles Schlotterbeck, chairman of the news committee during the preceding year, and by reports from representatives of the various branches present at the meeting of the activities in which each branch participated during the preceding year.

In the election of officers of the National Student Branch for the year 1935-36, the following were elected: President, Paul N. Doll, University of Missouri; First Vice-President, J. N. Maxwell, University of Georgia; Second Vice-President, Philip E. Brintenall, Iowa State College; Secretary, E. Robert Curry, Pennsylvania State College; Treasurer, J. H. Zich, A. & M. College of Texas.

Applicants for Membership

The following is a list of applicants for membership in the American Society of Agricultural Engineers received since the publication of the July issue of AGRICULTURAL ENGINEERING. Members of the Society are urged to send information relative to applicants for consideration of the Council prior to election.

T. C. Anderson, junior agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Minden, La.

R. Garman Broaddus, camp engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) ECW Camp No. 1, High Point, N. C.

Carlton Crownover, planning engineer for CCC Camp, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Lindale, Tex.

Miguel Echegaray, agricultural engineer, Spanish Embassy, 2700 15th St., N.W., Washington, D. C.

Floyd S. Edmiston, chief agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Minden, La.

J. M. Fielder, agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Ruston, La.

John H. Foreman, junior technical foreman, ECW Camp No. 18, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 501 Fort Ave., Minden, La.

C. A. Frye, district supervising engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 120 Nichol Ave., New Brunswick, N. J.

Russell W. Granberry, surveyor, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Imperial Hotel, Minden, La.

Harry J. Hammet, technical engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Ruston, La.

John H. Hogan, technical foreman (engineer), ECW Camp No. 9, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 501 Fort Ave., Minden, La.

Edward L. Holmes, technical engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Ruston, La.

John H. Hudson, junior agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 115 Milledge Terrace, Athens, Ga.

William E. Hudson, instructor, agricultural engineering department, University of Georgia, Athens, Ga. (Mail) 115 Milledge Terrace.

Willard B. Jones, technical engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 403 S. Vienna St., Ruston, La.

Herbert L. McCall, assistant agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Ruston, La.

John D. McIntyre, junior agricultural aide, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Minden, La.

Louis H. Meeker, camp engineer, ECW Camp No. 14, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Imperial Hotel, Minden, La.

Louis D. Merrill, regional director, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Lindale Tex.

John W. Moncrief, Jr., technical engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Ruston, La.

Robert M. Moore, draftsman, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Imperial Hotel, Minden, La.

Dan H. Norton, College trainee, Project No. 19, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Princeton Road, Athens, Ga.

A. V. Osterberger, junior agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Box 516, Ruston, La.

John P. Proctor, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 455 Milledge Ave., Athens, Ga.

Donald L. Richardson, junior agricultural engineer, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 514 Richardson St., Minden, La.

James E. Smith, junior agricultural aide, Soil Conservation Service, U. S. Department of Agriculture. (Mail) Minden, La.

Otis E. Smith, partner and sales manager, Venice Plumbing Co., Venice, Fla.

Kenneth V. Stewart, Jr., junior technical foreman, ECW Camp No. 12, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 522 Sullivan St., Minden, La.

W. H. Strong, camp superintendent (ECW) Soil Conservation Service, U. S. Department of Agriculture. (Mail) Lindale, Tex.

Fred B. White, assistant agricultural engineer, farm products department, Tennessee Coal, Iron and Railroad Co., Birmingham, Ala.

James E. Wyche, Jr., junior technical foreman, ECW Camp No. 2, Soil Conservation Service, U. S. Department of Agriculture. (Mail) 514 Sullivan St., Minden, La.

TRANSFER OF GRADE

D. E. Blandy, rural service division, New York Power and Light Corporation, Albany, N. Y. (Associate Member to Member)

D. C. Heitshu, engineering department, J. I. Case Co., Racine, Wis. (Associate Member to Member)

D. A. Milligan, equipment sales engineer, Cleveland Tractor Co., Cleveland, Ohio. (Associate Member to Member)

Arthur W. Turner, editor, advertising department, International Harvester Co., 606 So. Michigan Ave., Chicago, Ill. (Associate Member to Member)

Agricultural Engineering Digest

(Continued from page 327)

ELECTRICITY IN THE GARDEN. Rural Electrif. and Electro-Farming, 10 (1934), no. 112, pp. 113-115, figs. 4. This article gives brief accounts of experimental work on the use of neon lighting and soil-heating cables.

Laboratory experiments conducted by a commercial lamp works showed that the neon light is suitable for plant treatment in greenhouses. It was found that with pure neon light an intensity of 40 foot-candles was enough for the leaf development of cucumbers and tomatoes. Cucumbers, however, grew far more rapidly under 100 than under 50 foot-candles. On the other hand, the total yield of cucumbers was greatest in the case of plants with low illumination, although the plants under higher illumination bore the first fruits. In both cases irradiation gave a considerable increase in the crop, the average increase being 19.6 per cent. The tomato plants, especially at maximum intensity of neon light, developed very strongly.

The experimenters concluded from their work that most greenhouse plants when treated with neon light for 8 hr per day require illumination of at least 50 foot-candles of light. Lower intensities in most cases produced very little effect, the exception being cinerarias.

Experiments were also conducted with strawberry plants, and it was found that hothouse strawberries when irradiated with neon light not only yielded a more abundant crop but could be brought to the fruiting stage much earlier than usual.

In view of the success of the experimental work a special neon lamp for greenhouse work is now being manufactured. The equipment consists of neon tubes which are housed in elongated narrow reflectors. The reflector casts the light on the plants and by varying the height of the reflector above the plants the correct light intensity is obtained. The equipment can be used at a distance of from 2 to 7 ft from the plants according to whether a weak, medium, strong, or very strong intensity is required.

PILE TRESTLES AS CHANNEL OBSTRUCTIONS, *D. L. Yarnell.* U. S. Dept. Agr., Tech. Bul. 429 (1934), pp. 26, pls. 4, figs. 7. This bulletin presents the results of 1,082 experiments on the effect of clean pile trestles in obstructing the flow of water which were conducted by the USDA Bureau of Agricultural Engineering in cooperation with the University of Iowa. The purpose of the tests was to determine the coefficients for use in certain hydraulic formulas for calculating the backwater caused by such obstructions. The tests were conducted on both small size models and on full size single and double track pile trestles.

The results showed that the amount of obstruction to flow offered by pile trestles may be determined through the use of the proper trestle coefficient in any of the approved formulas. The detrimental effect of setting trestle bents at an angle with the current is less than might be expected. Little decrease in the coefficient, and hence in discharge, occurs unless the angle of the bent with the current exceeds 10 deg. The discharge coefficient for trestle bents set at a 30-deg angle with the current is about 4 per cent less than that for bents parallel to the current. Some beneficial effect can be obtained by setting trestle bents in echelon if a roadway must cross a stream at an angle. If the axis of the roadway is at a 60-deg angle with the current and the bents are set in echelon, the Nagler and D'Aubuisson coefficients are about 5 per cent greater than those for the same trestle crossing the stream at right angles to the current and the bents parallel to the current.

The pile trestle coefficients recommended for use in bridge pier formulas are as follows:

Arrangement of trestle	Pile-trestle coefficients D'Aubuisson $K_{D'A}$	Nagler K_N	Rehbock δ_o
Bents in line with current:			
Single-track, 5-pile trestle bent	0.99	0.90	5.77
Double-track, 10-pile trestle bent	0.87	0.82	11.90
2 single-track, 5-pile bents offset	0.85	0.79	13.00
Bents at angle with current:			
Single-track, 5-pile trestle bent at—			
10-deg angle	0.99	0.90	5.70
20-deg angle	0.96	0.89	7.50
30-deg angle	0.92	0.87	9.30

Appendixes include an analysis of the D'Aubuisson formula and a comparison of the accuracy of the D'Aubuisson, Nagler, and Rehbock formulas.

(Continued on page 332)

Design and Construction of Sodded Terrace Outlet Channels

(Continued from page 322)

By setting up a suitable form for the tabulation of calculated values with this method of solution by simultaneous quadratic equations, the necessary cross section of a channel with any desired side slope and for any desired optimum velocity may be quickly computed for any given slope and quantity of runoff. Solution of such a problem without employing simultaneous quadratic equations involves the use of a trial-and-error method.

CONSTRUCTION OF SODDED CHANNELS. For the excavating and rough grading of channels to be sodded, we have used a No. 2 Caterpillar terracer drawn by a 35-hp tractor, and this equipment has been very satisfactory for this purpose. Channels should be excavated to a depth such that the sod when placed will be not less than 8 inches below the terrace channel, and that fall protected by a short sodded slope at the entrance to the channel. Terrace channels in this area have averaged about 12 inches cut below the ground line. Where cultivated areas adjoin the channel, the spoil banks are spread with the grader so that after plowing the contoured rows may drain into the outlet channel and not tend to create gullies along the outside of the spoil bank.

After the rough grading with power equipment has been completed, the channel bed is fine-graded by hand until at all sections the channel bed is as level (crosswise) as it can be made, and the side slopes are not greater than 1½ to 1.

If the channel is to be protected by strips of sod, trenches are then laid off and excavated 12 inches wide, 5 inches deep, and 4 feet on centers, extending far enough up the banks on each side to provide a margin of safety above any expected depth of water. About 1½ inches of mixed topsoil and manure is then placed in the bottom of each trench. Sod is cut 3 inches thick and 12 inches wide with a sod cutter from a level meadow with as dense and pure a stand of Bermuda grass as can be obtained. Grazed sod is much better than ungrazed for this purpose. The sod is cut into strips 8 feet in length, loaded on 1-by-10-inch-by-8-foot boards, hauled to the channel, and the strips placed by tilting the boards and sliding the unbroken sod strip into the trench. The sod is then thoroughly tamped and covered with soil.

The strip-sodding method without auxiliary spreaders has been satisfactory on the lower slopes if carried out as described, but there has been very little, if any, difference in cost as compared to solid sodding. For this reason the latter method is recommended wherever the supply of suitable sod is adequate.

If a channel is to be protected by solid sodding the rough-grading and fine-grading operations are carried out in the same manner as for strip-sodding, except that it is necessary to cut the outlet channel at least 4 inches deeper to allow for the thickness of the sod and the layer of topsoil and manure, which is spread 1½ inches thick all over the channel bed and sides. The sod is cut and hauled in the same manner, the strips being laid side by side and packed closely together, finishing with a thorough tamping. Much of our sodding work was done during the winter season, with no apparent damage from temperatures as low as 9 degrees F above zero.

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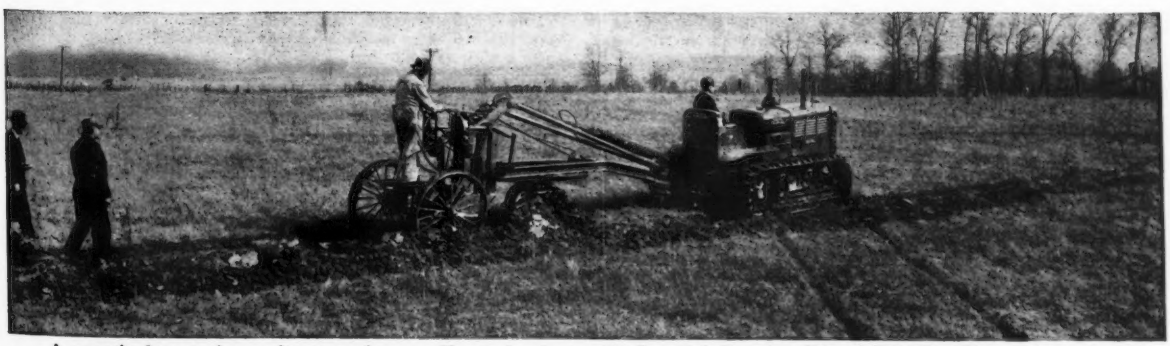

A practical terracing unit at work on a Kentucky farm—McCormick-Deering Diesel TracTracTor and terracer

McCORMICK-DEERING DIESEL

Agricultural Engineering Digest

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INVESTIGATION OF WARM AIR FURNACES AND HEATING SYSTEMS, VI, *A. P. Kratz* and *S. Konzo*. Ill. Engin. Expt. Sta. Bul. 266 (1934), pp. 128, figs. 50. This is the ninth progress report of these investigations and relates to the sixth feature of the work.

In a preliminary study of forced air heating systems, it was found that the installation of dampers is necessary in order to obtain proper heat supply and temperature balance in the rooms. The use of branch ducts as small as 3 by 10 in in connection with much larger ducts, is not to be recommended on account of the excessive drop in temperature of the air flowing in such ducts. A high bonnet and large ducts at the bonnet act as a plenum chamber and serve to equalize the temperature of the air at the outlets from the bonnet. A certain amount of gravity action takes place in a forced air system during the off period of the fan. Most of this action occurs in ducts leading to second and third stories and complicates the problem of control for such systems.

Studies of the performance characteristics of forced air heating systems showed that considerably higher capacity and furnace efficiency for given combustion rates may be obtained with a forced air system than with a gravity plant. The high furnace efficiency in a forced air system as compared with that for a gravity plant is not reflected as an increase in overall house efficiency or as a saving in fuel required to heat the house. The fuel consumption is practically independent of the volume of air circulated and of the type of control used in these tests. With continuous fan operation temperatures 1 to 2 deg F higher near the floor and lower near the ceiling are obtained than the corresponding temperatures for a gravity plant. With intermittent fan operation no marked improvement of the temperature near the floor occurs, but temperatures near the ceiling are approximately 1 deg lower than those for the gravity plant.

Studies of pressure losses in forced air heating systems showed that static pressures measured in various parts of a forced air system are meaningless unless interpreted in the light of changes in air velocity as well as of friction and shock losses. Owing to the presence of shock losses, the magnitudes of which are largely uncertain, complete and exact advance estimation of the pressure losses in a forced air system is practically impossible, and the actual pressures under which the plant operates may differ considerably from the predicted or estimated pressures on which the design of the plant was based, without impairing the usefulness of the plant or preventing satisfactory adjustment and operation. In the design of a forced air heating system a generous allowance should be made for the effect of dampers, particularly on the warm air side. Such dampers may have to be set to offer a very high resistance in some of the worst or longest runs to take care of an unforeseen condition introduced by a poor branch.

Tests of pressure losses through air filters in the forced air systems showed that the resistance of filters depends on the type of filter and on the closeness of the weave or the compactness of the material used in their construction. The total resistance in the system depends on the type of filter, the method of installation, and the quantity of air passed per filter. The resistance of a filter increases progressively but not uniformly with the time of service.

Tests of automatic control systems for forced air heating systems showed that the room air temperature may best be maintained within definite limits by operating the fan from the room thermostat (through a fan relay). For ideal operation the operating range of bonnet air temperatures should be varied either manually or automatically to correspond to the heating demands of the house. The most satisfactory operation of the heating plant required the maintenance of a uniform combustion rate just sufficient to supply the heating demands made on the furnace. This requirement involves frequent openings and closings of the furnace damper and can best be fulfilled when the damper operation is dependent on both the room temperature and the bonnet air temperature. This is equally true for both gravity and forced air systems. In systems using intermittent fan operation uniformity in the length of the on- and off-periods of the fan is necessary in order to maintain equal temperatures in the different rooms. With control systems involving intermittent operation of the fan it should be started between four and eight times per hour in order to obtain satisfactory regulation and equal temperatures in the different rooms. Continuous operation of the fan is advantageous in that it results in high bonnet efficiency, minimum air stratification, and low heat losses from the ducts. The total power required for intermittent fan operation varies from 10 to 100 per cent of that required for continuous fan operation. In the case of intermittent operation the power required to start the fan contributes an additional load varying from 3 to 27 per cent in excess of the normal running load over a range of indoor-outdoor temperature differences of from 20 to 60 deg. The fuel consumption and overall house efficiency are practically the same for intermittent fan operation and for continuous fan operation. A stack limit thermostat arranged to prevent flue gas temperatures from exceeding a predetermined upper limit can be successfully used to limit the combustion rate during periods of sudden load demand.

Tests of furnace bonnets and baffling showed that cylindrical bonnets with straight vertical sides and flat top and bonnets shaped like a truncated cone are equally effective and are better than straight-sided, flat-top bonnets which are only 7.75 in above the radiator. The use of an annular baffle in the casing has no detrimental effect at combustion rates below 2.5 lb per square foot per hour and improves the capacity and efficiency at combustion rates above 2.5 lb per square foot per hour.

Studies of warm air registers located near the ceiling and near the floor showed that high side wall registers with the common type of grills when operated with low air velocities comparable with those practical for baseboard registers cause excessive stratification of the air in the room, resulting in high air temperatures in the part of the room above the 5-ft level. High side wall registers with the common type of grills should not be used with the average velocity of the air at the register face less than 500 ft per minute. Deflectors or louvers at the register face of high side wall registers, set to direct the air at an angle of 45 deg downward, overcome stratification of the air in the room but may produce objectionable air currents in front of the register. The use of vertical diffusers in addition to the horizontal louvers in connection with high side wall registers is of no material advantage. Intermittent fan operation in connection with high side wall registers results in greater stratification of the air in the room than that occurring with continuous fan operation. Intermittent fan operation in connection with baseboard registers equipped with louvers set at 15 deg downward does not result in greater stratification of the air in the room than that occurring with continuous fan operation.

Baseboard registers with the common type of grills should not be operated with air velocities at the register face greater than 300 ft per minute. Baseboard registers with louvers at the face set downward at an angle of 15 deg with the horizontal effectively eliminate air stratification in the room and permit the use of air velocities at the register face as high as 500 ft per minute without the air currents becoming objectionable. With a baseboard register the addition of diffusers to deflect the air outward 15 deg from a central vertical plane and downward 15 deg below the horizontal does not materially reduce the air temperature near the ceiling or increase it near the floor, but it does permit the use of air velocities at the register face as high as 800 ft per minute without the air currents becoming objectionable.

Studies also are reported of the performance of two types of air washers and of heat emission from various surfaces. In the latter studies it was found that in the case of uninsulated metal surfaces transmitting heat to air the nature of the metal and thickness of the wall may bear little or no relation to the heat transferred. The character of the surface finish is a major factor in determining the heat transferred, bright metal surfaces transmitting less heat than rusty metal or painted surfaces. Thin layers of insulation placed on bright metal surfaces transmitting heat to air may result in increasing the heat transferred. Such surfaces should be covered with the equivalent of at least 0.25 in in of good insulation. Crimped asbestos paper has the same characteristics as plain asbestos paper when used as a heat insulator.

HARVESTING ALFALFA WITH A WINDROW PICK-UP BALER, *J. B. Davidson* and *W. H. Carter*. Iowa Sta. Bul. 322 (1934), pp. 201-216, figs. 8. This bulletin reports the results of experiments with a windrow pick-up baler. It was found that excellent quality hay may be made with this machine.

It was found in the tests that efficiency in the operation of the baler is largely dependent upon two factors—(1) a windrow of sufficient size to furnish hay at a rate near the capacity of the machine but not so fast as to necessitate stops, and (2) the skill of the operators, particularly of the feeder and the bale tier.

An estimate of the cost of baling when 1.59 tons per hour were baled was $2.17 per ton. Increasing the capacity to 2.75 tons per hour lowered the estimated cost to $1.42 per ton. An average of 4.5 hp was required from the power take-off of the tractor to operate the baler. A drawbar pull of 850 lb was required to draw the baler on level ground. In operating the baler an independent clutch for the power take-off would be very convenient. An auxiliary engine to operate the baler would furnish the same advantages.

Hay baled directly from the windrow will store satisfactorily if the water content is sufficiently low. Hay containing as much as 23 per cent moisture can be baled with reasonable safety, although under some conditions there might be sufficient heat developed to result in a loss of color and a lowering of the grade. The windrow pick-up baler presents a good opportunity for saving a large proportion of the leaves of the alfalfa plant. *(Continued on page 340)*

Tunnels in the mountains must meet accurately

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ATLAS

EXPLOSIVES

ATLAS EXPLOSIVES

Agricultural Engineering Digest

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THERMAL DECOMPOSITION OF HYDROCARBONS AND ENGINE DETONATION, *F. O. Rice.* Indus. and Engin. Chem., 26 (1934), no. 8, pp. 259-262. fig. 1. The results of studies conducted at Johns Hopkins University are reported which indicated that the thermal decomposition of the fuel probably plays an appreciable role in the reactions occurring in the internal-combustion engine. This decomposition results in one molecule of the fuel being replaced by several molecules. This increase in concentration may greatly augment the rate of oxidation. Different hydrocarbons yield different numbers of molecules of products per mole decomposed, and calculation shows a strict parallelism between this and the knocking tendency. The knocking tendency increases with increase of number of moles of product per mole decomposed. One effect of anti-knock compounds is to reduce the number of moles of products formed from the decomposition of one mole of hydrocarbon.

ELECTRIC BROODING OF CHICKS—I, HEAT REQUIREMENTS, *W. T. Ackerman, T. B. Charles, G. M. Foulkrod, A. E. Tepper,* and *F. D. Reed.* New Hampshire Sta. Circ. 46 (1934), pp. 16, figs. 7. Experiments are reported in which the brooding of chicks by electricity in colony brooder houses was successfully carried out through the winter and spring of 1933-34.

One of the coldest winters on record was experienced, the temperature going as low as 30 deg F below zero, and for several days at a time the average for a 24-hr period was approximately zero. Notwithstanding this extreme temperature, the losses were reasonable.

The growth of chicks was very favorable, uniformity was in evidence, and feathering was somewhat more rapid than in similar lots under hot water brooding. Comparisons between chicks in insulated and noninsulated houses with reference to feed consumption, weight gains, condition of chicks, condition of litter, and kilowatt-hours of electricity consumed showed practically no differences. The use of insulation on walls and ceilings seemed unwarranted.

It was found that during extremely cold weather the litter just outside the edge of the hover became so damp, due to moisture condensation, that frequent removal was necessary. There was not sufficient heat loss from the electric brooder to evaporate moisture so deposited.

The 4 houses used in this study were of the individual colony type, 2 having shed roofs and 2 having combination gables.

TRENCH SILOS, *R. C. Miller.* (Ohio Sta. Bimo. Bul. 171 (1934), pp. 205-207). Practical information is given on the construction of trench silos for Ohio conditions.

FLOODS AND ACCELERATED EROSION IN NORTHERN UTAH, *R. W. Bailey, C. L. Forsling,* and *R. J. Becraft.* U. S. Dept. Agr. Misc. Pub. 196 (1934), pp. [2] + 21, figs. 9. The studies reported in this publication were conducted by the Intermountain Forest and Range Experiment Station in cooperation with the Utah Agricultural Experiment Station and the geology department of Utah State Agricultural College. The purpose is to present geologic evidence of flood damage and to point out that the recent floods in northern Utah constitute abnormal run-off and accelerated erosion, thereby marking a radical change from the normal rate of gradation of the present geologic epoch and climate. Evidence also is presented tending to show that this condition can be attributed chiefly to the depletion of the plant cover on the watersheds of the drainages involved.

RESEARCH ON METALS AND ALLOYS, *F. C. Frary.* Indus. and Engin. Chem., 26 (1934), no. 8, pp. 281-284. A summary of data is presented on the effect of impurities in metals, workability, problems of melting metals, customers' problems, casting processes, and corrosion problems.

It is pointed out that there are two fundamental objectives in research on metals and alloys. The first involves the investigation of the complex physicochemical intermetallic systems and the effects of variations in temperature, minor impurities, and other variables upon such systems. The second objective comprises the improvement of available alloys and metals to make them more widely adaptable or useful and the discovery of possible new and useful alloys. Experience shows that the second of these objectives cannot be pursued to the best advantage without a simultaneous pursuit of the first.

KNOCKING CHARACTERISTICS OF HYDROCARBONS, *W. G. Lovell, J. M. Campbell,* and *T. A. Boyd.* Indus. and Engin. Chem., 26 (1934), no. 33, pp. 1105-1108, figs. 4. This paper presents data on the knocking characteristics of 103 hydrocarbons, including paraffin, naphthene, and aromatic compounds. The measurements were made in the pure state and are expressed in terms of engine compression ratio at incipient knock under definite conditions of engine operation. Such critical compression ratios vary over a range of about 14 ratios. The qualitative general correlation between knocking characteristics and molecular structure previously found for such hydrocarbons when measured in dilute solutions were found to hold in general, with some notable exceptions. These arose from the fact that the compression ratio of a mixture of two compounds is not always directly proportional to concentration.

LUBRICATING OILS FROM ETHYLENE, *R. G. Atkinsn* and *H. H. Storch.* Indus. and Engin. Chem., 26 (1934), no. 33, pp. 1120-1122, figs. 3. Studies conducted by the U. S. Bureau of Mines are reported which indicate the possibility of producing a good light lubricant from the lower members of the olefin series by a 2-stage process, the first step being a thermal polymerization to a liquid boiling in the gasoline range. The material produced in this manner can then be polymerized by aluminum chloride to a viscous liquid suitable for a lubricant.

EROSION CONTROL STRUCTURES—DROP INLETS AND SPILLWAYS, *L. H. Kessler.* Wisconsin Sta. Res. Bul. 122 (1934), pp. 66, figs. 37. This bulletin presents the results of an analysis of the hydraulic characteristics of certain types of concrete conduits, flumes, and spillways used with earth-filled soil-saving dams for erosion control. It was prepared by the Wisconsin Agricultural Experiment Station and the engineering experiment station of the University of Wisconsin in cooperation with the USDA Forest Service and the Wisconsin Civil Works Administration.

The structures analyzed included drop inlets, notch spillway, head flume, and head spillway. A large amount of engineering information is presented but not in form for brief presentation.

THE PROTECTION OF JOINTED WOOD PRODUCTS AGAINST DECAY AND STAIN, *E. E. Hubert.* Idaho Univ. School Forestry Bul. 4 (1934), pp. 36, figs. 10. Studies are reported the purpose of which was to develop methods of protecting wood joints against decay and stain.

It was found that the number of actual failures of wood joints which are traceable to decay and stain are small and the losses are greatly exaggerated. The tests included laboratory tests, rot cellar tests, and laboratory paint tests. The results point to the use of any one of three types of protective measures, including (1) a toxic, penetrating chemical compound applied to a part of or to the entire product or inserted in a shallow cup in the tenon of the joint, (2) a water-repellant compound possessing high penetrating qualities applied as in 1, and (3) an effective combination of 1 and 2. The 10 compounds found most effective in the laboratory and rot cellar tests are listed.

TESTS SHOW MERITS OF BUTANE AS AN INTERNAL-COMBUSTION-ENGINE FUEL, *C. J. Vogt.* Automotive Indus., 71 (1934), no. 12, pp. 348-351, figs. 8. The results of studies conducted at the University of California are reported which involved a program of study on engine operating characteristics with various hydrocarbon fuels.

It was found that the brake mean effective pressure at 1,000 rpm was much higher for butane-air mixtures than for gasoline-air mixtures. Maximum brake mean effective pressure was found to occur nearer the theoretical air-to-fuel ratio for complete combustion when using butane than when using gasoline, indicating a more homogeneous mixture for butane and air than for gasoline and air.

Although the brake mean effective pressure was higher for butane-air mixtures, the economy was less than for gasoline, especially at the higher compression ratios. However, it is pointed out that at the present price of butane this fuel has a great advantage over gasoline on the basis of fuel cost.

Spark adjustment for best performance was found to be practically the same with butane and gasoline.

PERMEABILITY TESTS OF 8-IN BRICK WALLETTES, *L. A. Palmer* and *D. A. Parsons.* Amer. Soc. Testing Materials, Preprint 57 (1934), pp. 13, figs. 3. A total of 240 wallettes made with 10 representative mortars and 5 makes of bricks were aged for 3 mo and tested for permeability by keeping a constant level of water in a shallow reservoir (1 in in depth) on the upper surface (face) of each test specimen. Each wallette was constructed with 16 bricks (both header and stretcher bricks) and the mortar joints were approximately ½ in in thickness. The most watertight walls were obtained with smooth impervious bricks set dry and smooth porous bricks set wet (15 min total immersion). The degree of watertightness of the wallettes was also dependent on the working properties of the mortars. *(Continued on page 342)*

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Agricultural Engineering Digest

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FRICTION TESTS ON LUBRICATING OILS, *J. W. Donaldson* and *D. R. Hutchinson*. Jour. Soc. Chem. Indus., Trans., 52 (1933), no. 49, pp. 424-429, figs. 9. The results of studies are reported the purpose of which was to ascertain if an extremely simple mechanical arrangement could be devised which would give discriminating results with oils of comparative specifications.

The apparatus used for testing consists essentially of a ball resting in a spherical seat. The ball is attached to a weight at the end of a rod so that the whole forms a pendulum which can be oscillated on the fixed spherical seat. The pendulum is swung through a definite angle by means of a releasing gear at the lower end, and on a scale supported above the seat the angle of swing of the pendulum is determined. Two drops of oil are sufficient to lubricate the surface between the ball and seat. To determine changes taking place in the properties of the oil on heating, the seat is converted into an electric heating unit.

The results obtained with animal, vegetable, and mineral oils were in general agreement with those of other investigators as regards the behavior of fixed and mineral oils under conditions of boundary lubrication. It was found that the behavior of mineral oils, whereby their coefficient of friction increases as the viscosity decreases on heating, may possibly be attributed to the increasing number of asperites in the bearing which would be brought into contact by the lowering of the viscosity. In this connection it is suggested that the asperites are of molecular proportion.

The decrease in the coefficient of friction at high temperatures of the fixed oils suggests a chemical change whereby a new chemical state occurs at the points of approach. The persistence of a lubricating film at very high loads leads to the supposition that an adsorption film operates on the surface.

In the various bearings dealt with, frictional resistance appears to be due to two factors, namely, an increased frictional rate due to decreasing viscosity on heating and an increasing adsorption rate depending on the nature of the oil. In mineral oils the rates might equalize at high temperatures to give a constant coefficient of friction, and in fixed oils with a high adsorption rate, such an adsorption rate might be greater than the increased frictional rate due to decreasing viscosity and lead to a decrease in the coefficient of friction.

RELATION OF DIGGER OPERATION TO POTATO TUBER INJURY, *E. V. Hardenburg*. Amer. Potato Jour., 11 (1934), no. 7, pp. 171-176. The results of studies conducted by the New York [Cornell] Agricultural Experiment Station are reported in which it was found that about 10 per cent of the potato crop grown in New York in 1931 and 1932 was mechanically injured by the digger.

It was found that the standard makes of diggers in common use appeared to be equally efficient in respect to tuber injury. About 85 per cent of the elevator diggers used in New York in 1931 and 1932 were equipped with rear attachments. The other 15 per cent equipped with a continuous apron resulted in 35 per cent less bruising of the tubers. On 88 diggers equipped with rear attachment, the drop from front to rear attachment ranged from 11 to 18 in. For each increase of 2 in in drop the number of bruised tubers increased 2.7 per cent. The percentage of bruised tubers was found to be in inverse relation to the amount of soil carried on the digger chain. The amount of soil carried on the digger chain was found to be in inverse relation to speed of operation and in direct relation to the depth of digging.

Height of row ridge on 254 farms varying from 2.5 to 9 in seemed to bear no relation to tuber bruising. It is therefore assumed that ridging has no direct effect on the amount of soil carried by the digger. Increase in height of ridge was associated with a reduction in the percentage of cut tubers. This may be due to the fact that tubers set higher under ridge than under level culture.

A test of digger operation under controlled conditions demonstrated that reduced speed of the digger chain and deeper setting of the digger are equally effective in avoiding tuber injury. The digger equipped with a continuous elevator bruised about 60 per cent fewer tubers than when the same digger carried a rear elevator.

GOVERNMENT TESTS DISTILLATE BURNERS, *A. H. Senner*. Fuel Oil Jour., 13 (1934), nos. 5, pp. 46, 47, 49, 50, figs. 13; 6, pp. 45, 46, 51, 52. In a contribution from the USDA Bureau of Agricultural Engineering, a series of tests are reported which constitute part of the information available on distillate oil burners. These burners were tested in a coal-burning range, and the range itself was tested with coal to provide a basis for comparison with the results obtained when fired by the several range burners under investigation. A large amount of data are presented but no definite conclusions are drawn. *(Continued on page 344)*

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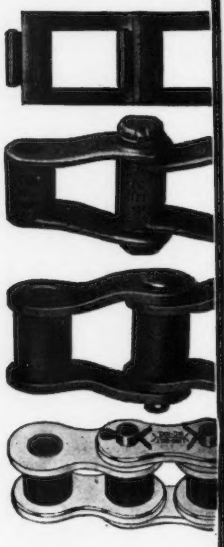

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FUEL FROM SEWAGE AND CELLULOSIC WASTE, *R. E. Hussey, S. B. Row,* and *W. W. Allison.* Va. Engin. Expt. Sta. Bul. 18 (1934), pp. 50, figs. 8. The results of an investigation are reported the purpose of which was to determine whether or not the amount of gas generated during the digestion of sewage solids at the sewage disposal plant of the Virginia Polytechnic Institute would be sufficient to supply the requirements of the college laboratories. Studies also were made to determine the increase in gas production by adding certain cellulosic wastes to the digestion tank.

It was found by controlled experiments that digestion at 25 deg C produced 9.3 cu ft of gas or 5.9 cu ft of methane per pound of dry suspended solids. Thus it should be possible by heating the plant digestion tank to 25 deg to obtain an average of 3,125 cu ft of gas, or 1,972,090 Btu per day. It was shown by experiments that by the addition of about 17.2 per cent waste paper, the gas production could be increased by 10.7 cu ft of gas, or 5.2 cu ft of methane per pound of paper. Therefore, by the use of 60 lb of waste paper per day the average gas production at the plant could be increased to 3,767 cu ft of gas, or 2,282,530 Btu per day. The gas requirements of the college laboratories for 1931 amounted to from 728,864 to 974,932 Btu per day. If the gas generated at the Virginia Polytechnic Institute plant were collected and used by the college laboratories there would be an excess available for heating the digestion tank of from 997,158 to 1,243,227 Btu per day. By the addition of 60 lb of waste paper per day this excess would be increased to between 1,317,598 to 1,553,667 Btu. Peanut hulls in addition to the digestion tank produced 1.5 cu ft of gas, or 0.58 cu ft of methane per pound. Extracted leaf waste digested easily and gave a yield of 3.9 cu ft of gas, or 2.3 cu ft of methane per pound of waste.

THE TREATMENT OF LAUNDRY WASTES, *J. A. Boyer.* Tex. Engin. Expt. Sta. Bul. 42 (1933), pp. 15. Studies are reported the results of which indicate that a trickling filter rather than chemical methods or a Dunbar filter should be used to treat laundry wastes.

It was found that a trickling filter 6 ft deep, operating at a rate of 1,000,000 gal per acre per day and treating a raw waste with an average biological oxygen demand of not over 450 ppm, will produce an effluent suitable to discharge into a stream or storm sewer. A 75 per cent reduction of biological oxygen demand may be expected.

Ferric sulfate, ferric chloride, and aluminum sulfate will reduce the biological oxygen demand of laundry waste from 90 to 95 per cent and produce a satisfactory effluent. Sludge and scum will be troublesome by-products. Careful adjustment of pH value of the raw waste to 6.6-6.4 is necessary for economical results with chemicals.

On account of the necessity of fine screening the applied waste, the troubles caused by clogging, and the inferior effluent produced, the Dunbar filter is not recommended for the treatment of laundry waste.

TERRACING IN ALABAMA, *A. Carnes* and *J. B. Wilson.* Ala. Polytech. Inst. Ext. Circ. 148 (1934), pp. 20, figs. 12. Practical information is presented on useful terracing practices adapted to Alabama soil conditions. It is based on the results of studies conducted at the Alabama Agricultural Experiment Station. The methods of erosion control combine the use of terraces and vegetation as strip crops.

It has been found that the so-called Nichols' terrace is the most satisfactory for Alabama conditions. It consists essentially of a broad, shallow ditch, with a moderate sized mound on the lower side. Since this terrace carries most of the water below the surface of the ground, complete failures rarely occur.

EMPLOYMENT BULLETIN

An employment service is conducted by the American Society of Agricultural Engineers for the special benefit of its members. Only society members in good standing are privileged to insert notices in the "Positions Wanted" section of this bulletin, and to apply for positions advertised in the "Positions Open" section. Non-members as well as members, seeking men to fill positions, for which members of the Society would be logical candidates, are privileged to insert notices in the "Positions Open" section and to be referred to persons listed in the "Position Wanted" section. Notices in both the "Positions Wanted" and "Positions Open" sections will be inserted for one month only and will thereafter be discontinued, unless additional insertions are requested.

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